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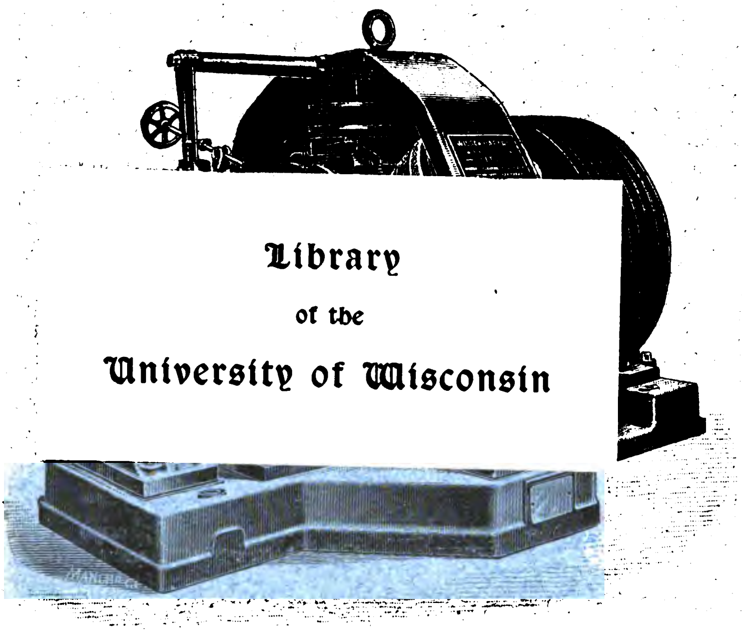

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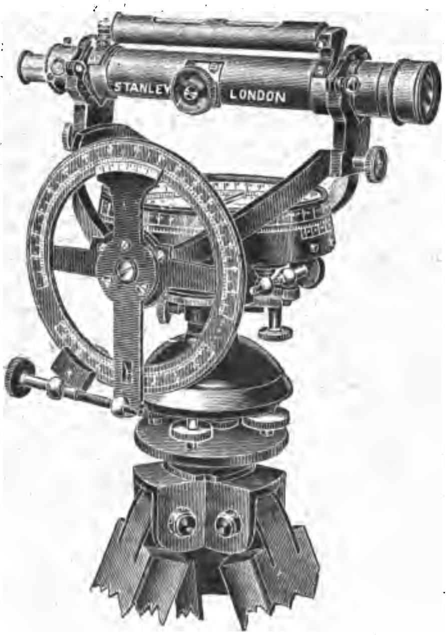

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ELECTRICITY
AS
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BY

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PREFACE

TWENTY-FIVE years ago the use of Electricity in Mining was confined to signalling and shot-firing; twenty years ago the pioneers of electric lighting and electric power transmission had this wonderful agent already at work in a few mines in various parts of the world; since then numerous improvements have greatly facilitated its adoption; and to-day the use of electricity in and about mines has become so widespread—both for lighting and as a mode of transmitting power—that a demand has arisen for a text-book dealing especially with the subject in relation to its mining applications.

So many are the subjects to be studied in the vocation of the mining engineer or colliery manager, that it is impossible within the limits of a treatise on Mining to deal adequately with such an important subject as Electricity; and, on the other hand, the many excellent books which deal solely with Electricity, having been written mainly for the electrical engineer, necessarily go further into the subject than the mining engineer requires in most cases.

The aim of the authors of the present volume has been to present to the reader the leading truths and main principles of electricity and electrical engineering without going into great detail, their intention being that he should have recourse for further information on the theory and practice of the subjects of Electrical and Mining Engineering to some of the many standard works already in existence. They are unable (it need hardly be said) in the space at their disposal to deal with all the varieties of machines and appliances now in use, typical examples of good practice being considered sufficient for the present purpose.

In a book of this nature, with its 'electrical' side and its 'mining' side, joint authorship is, if not absolutely essential, at least advantageous, for the electrical engineer and the mining engineer must work hand in hand if success in electrical operations is to be achieved.

The authors desire to thank the numerous friends and manufacturing firms who have so courteously supplied them with information, the loan of blocks, &c. Wherever possible, such assistance is acknowledged specifically in the text.

In conclusion, the authors may express the hope that the work will be found of practical service to those mining engineers, colliery managers, or others, who have already adopted or are contemplating the use of electricity for power or lighting; and they trust that those who use the book will kindly give them the advantage of any corrections, additions, or suggestions, with a view to making the book of more value to the class for whom it is intended.

LEEDS: *November*, 1902.

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ELECTRICITY

AS APPLIED TO MINING

CHAPTER I

INTRODUCTORY

Introduction to the Subject of Electricity—The Electric Current—The Electric Circuit—Electric Terms—Volt, Watt, Ampère, &c.—Chemical Production of Electricity—Primary and Secondary Cells.

UP to about the early seventies of the past century, little or no use, as a means of lighting and transmission of power, had been made of the subtle agent which we are pleased to term 'electricity.' Prior to that period, however, the scientific world had been laying down the fundamental principles which were to underlie, and play such an important part in, the development of the electrical engineering industry of to-day. Since then the possibilities of electricity have been realised, bringing a multitude of workers into the field of invention, with the result that we are at the present moment accustomed to see electricity employed for nearly all the purposes that earlier agents, such as steam, horses, &c., had been used for.

Before dilating on the applications of electricity for mining purposes, it will be necessary to consider in sufficient detail the nature, properties, method of measuring, and dealing with this agent.

The question which is uppermost in the minds of many, and which may naturally be asked, is, '*What is electricity?*' To this but a very indefinite answer can be given. In fact, no one really knows what it is. We are accustomed to see it in the form of lightning during a thunderstorm, when it is termed 'atmospheric electricity,' or to speak of electricity 'at rest' in the form of a *charge* on a body, which may be due to the body having been rubbed—as, for instance, the electrification produced by rubbing a glass rod with silk, both rubber and rod then having

the power of attracting light articles such as paper, pith, &c. This is termed 'frictional electricity.' We, however, more often speak of a '*current of electricity*' flowing through a body or conductor, and, as this expression will frequently be used throughout the present work, we will next proceed to qualify it.

The expression, 'current of electricity,' rather implies a flow of matter or something which has an independent existence apart from the conductor it is said to be flowing in; but in reality we do not in the least know whether anything is actually in motion in the conductor. Our senses do not help us in this respect, for nothing is visible save the conductor, which presents the usual appearance when the so-called *current of electricity* is flowing in it. To shortly state the matter, the expression is a purely *conventional* one, and when we use it, it is merely to indicate that the conductor and space around it exhibit effects and properties which they did not do before.

In this connection it should be remembered that the *direction of flow* is equally conventional, though the resulting effects have a definite sense or direction of action. It is, therefore, merely as a convenience that we regard electricity as capable of flowing in the form of a current along or in any conductor, and also in a definite direction along the conductor, depending on the sense in which the effects are produced.

The so-called *current* must, of course, follow some route or path, and, whatever be the nature of this, it is called the *electric circuit.*

All electric circuits, however, do not offer the same facilities for the passage of currents of electricity, some forming a great *obstruction*, or, in common phraseology, offering a great *resistance* to the flow, others offering very little.

In this connection it may be helpful to draw an analogy to a water-pipe, which, if partly stopped up with sand or sawdust, for instance, at some part of its length, would offer a far greater obstruction or resistance to the flow of water than if quite clear. Or, again, if the water had to flow through a water-motor inserted in the pipe, and possibly other appliances, the resistance to its flow would be greater than through the same length of clear pipe without these appliances. So it is with currents of electricity, the strength of which depends upon the nature of the path or circuit, whether simple or containing appliances through which it has to pass.

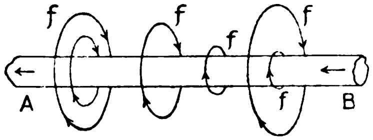
This analogy, though helpful in explaining the state of things met with in an electrical circuit, so much so that we shall again have to refer to it, must not be pressed too far, for it must be remembered that in a water-pipe we are actually dealing with matter in motion; but with electricity, motion, if it exists, is not apparent. To show that the analogy of water in a pipe must not be pressed too far, it will be sufficient to cite that while a pipe bent at right angles offers much more resistance to the flow of water

than when straight, an electrical circuit in which there is such a bend has no effect whatever on the strength of current flowing.

Effects or Properties of an Electric Current.—As, therefore, a current of electricity flowing in a circuit cannot be seen, we can only measure and judge of it by the effects produced. These come under the following headings :—

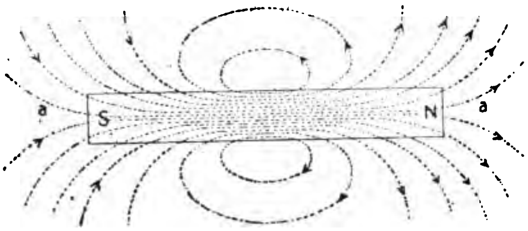
Magnetic.—This effect is produced whenever a current flows in a circuit, a magnetic field, consisting of lines of magnetic force, being set up around the circuit or path of the current. A reference to fig. 1 will perhaps make this clearer. Suppose a current to be flowing from B to A in the conductor, A B, then innumerable lines of magnetic force, *f*, encircle the conductor, concentric with it if A B is straight, but acting in the direction of the arrows in planes perpendicular to the conductor. The size of these circles will increase with the strength of the current, some being very large indeed, others very small. Their direction will reverse simultaneously with that of the current, and they are continuous, unbreakable, and invisible. The space pervaded by such lines of magnetic force is termed a *magnetic field*, and when a piece of iron, steel, nickel, cobalt, or manganese is pervaded by these lines or, which is the same thing, produces a magnetic field, it is said to be a *magnet*. These substances are therefore called magnetic substances. Fig. 2 shows what is usually termed a permanent bar magnet, the dotted lines indicating the kind of disposition or path, and the arrow-heads the direction, of the lines of force. Every line passes through

FIG. 1.



MAGNETIC FIELD OF CURRENT IN A WIRE.

FIG. 2.



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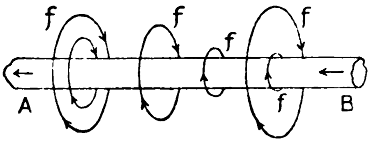

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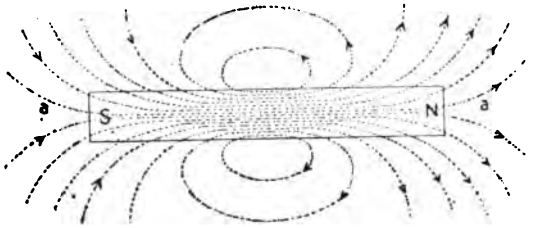

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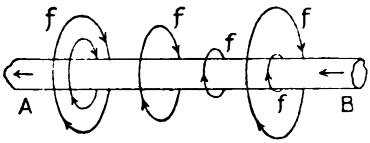

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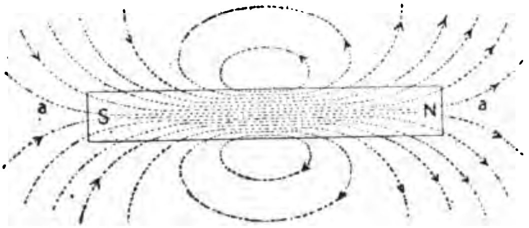


PERMANENT BAR MAGNET.

or pressure is entirely unaffected by a bend in the circuit, however sharp, when the current flow is steady. This shows that the analogy of the water system, as before mentioned, though helpful in understanding electrical pressure, &c., must not be pressed too far. A current of electricity will flow so long as any potential difference exists, and will cease when this is uniform throughout the circuit.

In all that follows we shall denote the extreme difference in pressure of any circuit by the term *Electro-motive force* (abbreviated to E.M.F.), while that between any other two points, which must necessarily be lower, by the term *Potential difference* (abbreviated to P.D.).

The unit of difference of pressure, or of E.M.F., is that difference of potential which must be maintained at the ends of any circuit of 1 ohm resistance so that a current of 1 ampère may pass through it. This unit is called a *Volt.*

We are now in a position to state the most important of all laws relating to current electricity, which was first enunciated by Dr. G. S. Ohm many years ago—namely, that *the ratio of* $\frac{\textit{potential difference}}{\textit{current}}$ *for any conductor at constant temperature is a constant*, and is equal to the resistance of the conductor, or, in ordinary parlance : If **R** is the total resistance in ohms of a circuit across which there is a P.D. of **V** volts, then the total current, **A**, in ampères flowing is

$$\mathbf{A} = \frac{\mathbf{V}}{\mathbf{R}} \text{ ampères;}$$

whence

$$\mathbf{R} = \frac{\mathbf{V}}{\mathbf{A}} \text{ ohms,}$$

or

$$\mathbf{V} = \mathbf{A}\,\mathbf{R} \text{ volts.}$$

This is a fundamental principle of the utmost importance, and is universally called '**Ohm's Law.**'

On page 5 reference was made to the heating effect of a current, and it was there stated that some heat is always generated by a current, however small, in flowing through a circuit of any nature whatsoever. This heat is the direct effect of the expenditure of electrical energy in the circuit, and is only another form of such energy. Heat is always generated when work is done through the expenditure of electrical energy, and it can be experimentally proved that the heat produced in a circuit of r ohms resistance when a current of A ampères flows through it is proportional, not only to A^2, but to r; *i.e.*, is proportional to A^2r.

If the unit of heat is taken as the amount of heat required to raise 1 lb. of water from 0° C. to 1° C., then the number of units of heat produced in t minutes is

$$H = 0{\cdot}0315\ A^2rt.$$

If the unit of heat is taken as the amount of heat required to raise 1 gramme of water from 0° C. to 1° C., called a French Thermal Unit, Calorie, or Therm, then the number of units of heat produced in t seconds is

$$H = 0{\cdot}239\ A^2rt \text{ calories.}$$

This is known as *Joule's Law*, and the heating effect as the *Joule Effect*. But J. P. Joule, the discoverer of this law, has shown that the above thermal unit is equivalent to about 1,400 foot-lbs. of work. Hence it A ampères flows at a P.D. of V volts through r ohms for t minutes, the work done,

$$\begin{aligned} W &= 1{,}400 \times 0{\cdot}0315\ A^2rt \\ &= 44{\cdot}25\ A^2rt \text{ foot-lbs.} \end{aligned}$$

But $$A = \frac{V}{r};$$

$\therefore$ $$W = 44{\cdot}25\ A\,Vt \text{ foot-lbs.,}$$

which relation is true for any kind of circuit; but since the power expended = rate at which work is done,

Power × Time = Work done;

and $\therefore$ the work done in foot-lbs. per min., or electrical power expended on the circuit, is 44·25 A V:

$$= \frac{44{\cdot}25}{33{,}000}\ A\ V = \frac{A\ V}{746} = 0{\cdot}00134\ A\ V \text{ horse-power.}$$

The **Unit of Electrical Power**, or unit rate of working, is called the **Watt**, and is that power exerted when 1 ampère flows under the pressure of 1 volt. Hence the English horse-power = 746 watts. The work done by 1 watt in one second is termed a *Joule.* Hence the work done in joules = watts × seconds = A^2rt.

1 calorie = 4·16 joules = 3·067 foot-lbs. = ·00396 British thermal units.

The **Unit of Electrical Energy** is termed the *Board of Trade* unit (B.O.T. unit), or kilo-watt-hour, and = 1,000 watt-hours. This is the commercial unit, in terms of which the electrical energy supplied to a consumer is measured or reckoned, and whenever the ampères × volts × time in hours or fractions of an hour in any combination whatsoever = 1,000, a B.O.T. unit of electrical energy is said to have been expended.

The **Unit of a Quantity of Electricity** is called a *Coulomb*, and is that quantity of electricity which flows past any point of a circuit conveying 1 ampère in one second. Or, 1 coulomb = 1 ampère per sec.; or, briefly, an ampère-second.

In actual practice multiples and fractions of each of the preceding units have to be dealt with, and these have received special names. Those in common use will therefore now be given to familiarise the reader with the terms used :—

A Milli-ampère = $\frac{1}{1000}$ ampère.
A Meg-ohm = 1,000,000 ohms.
A Microhm = $\frac{1}{1000000}$ ohm.
A Kilo-watt = 1,000 watts (commercial unit of electrical power).

It was remarked on page 8 that an electric current always continued to flow through a closed circuit, continuous in itself, so long as a difference of potential existed, in the same way that water continues to flow through a pipe as long as a difference of level (head) exists.

In the case of water some appliance must be provided for raising the water originally to the higher level—*i.e.*, for maintaining a *head* or difference of level.

The principle is precisely similar in the case of electricity, for in this a difference of potential must be maintained, and some appliance is necessary to raise and keep up the higher potential whence the difference will also be maintained. Such appliances are called current generators, of which the following are the chief types in practical use :—

(*a*) Primary cells.
(*b*) Secondary cells, also termed storage cells or accumulators.
(*c*) Dynamos.

All of these are merely appliances for converting various forms of energy into *electrical* energy ; for instance, in both primary and secondary cells it is potential chemical energy which is stored up and converted into electrical energy. In dynamos mechanical energy is transformed directly into electrical energy.

As each of the above sources is employed in connection with mining work, we shall now consider them somewhat in detail, restricting ourselves, however, to those forms and types most commonly met with in such work.

(*a*) Primary Cells.

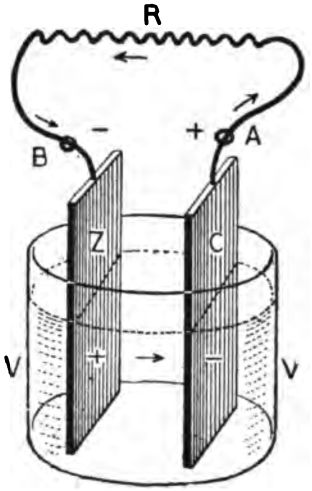
A primary cell consists of a vessel made of some non-electrically conducting material containing one or more acid or salt solutions, either mixed or separated by one of them being contained in an inner receptacle, in which are immersed two solid conducting bodies, one of these being more readily oxidised or acted on by the solution than the other.

Primary cells may be divided into two distinctive classes : (1) *Single fluid*, or those in which only one fluid is used, and (2) *Double fluid*, or those in which two fluids or solutions are used. There is, however, a third type of primary cell, which is a special form of the above, containing no solution at all and termed a 'dry cell.'

It will only be possible, in discussing primary cells in the following pages, to direct our attention to forms commonly met with in, and suitable for, mining work generally, whether for such purposes as telephony, telegraphy, blasting, &c. A very large number of types of these cells have been devised from time to time, some of which are now only of historic interest.

Single-fluid cells being the simplest of all, we shall take a typical example and point out its principle of action, advantages and disadvantages, &c.

FIG. 4.



SIMPLE VOLTAIC CELL.

Fig. 4 shows diagrammatically the construction of such a cell. It consists of a zinc plate, Z, and copper plate, C, dipping into an oxidising solution, such as dilute sulphuric acid, contained in a glass or glazed earthenware vessel, V.

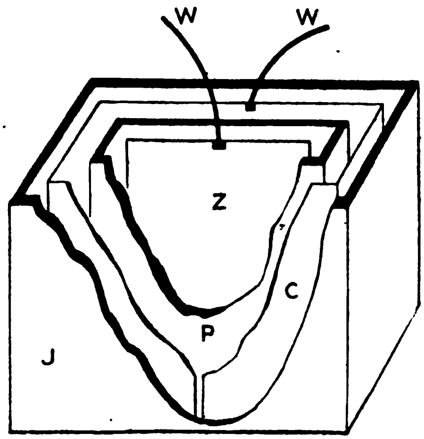
Two stout metallic connections join the plates to A and B respectively, which form the poles or terminals of the cell.

If the plates C and Z, particularly the latter, are practically pure, no action of any description takes place by reason of them dipping into the dilute sulphuric-acid solution; but if the two terminals A and B are connected to what is commonly termed an external circuit, R, an electric current at once flows in the direction of the arrows. The zinc plate, Z, is now observed to gradually waste away, and continues to do so as long as the circuit is complete through R.

required. The construction will be easily understood from fig. 5, which is one form of Daniell's cell with portions of the cell cut away to show the interior more clearly.

It consists of a zinc plate, Z, dipping into a solution of zinc sulphate or dilute sulphuric acid, contained in a pot, P, of porous or unglazed earthenware. This porous pot is surrounded by the copper plate, C, which is immersed in a solution of copper sulphate contained in an outer glass or glazed earthenware vessel or jar, J. The porous pot, P, merely separates the two solutions, but does not isolate one from the other. It, however, allows of the passage of the current from one plate to the other, and the solutions gradually diffuse and mix. There are many modifications of this form of Daniell, some of which are cylindrical. One that is compact, and takes up little floor or shelf space, is that used to a considerable extent in the Post Office service, and which is due to Dr. Muirhead. The cell is rectangular in shape, instead of being round, and the copper plate is placed in the porous pot, which is half filled with crystals of copper sulphate, and filled up to the top with water.

FIG. 5.



DANIELL'S CELL.

The zinc plate dips into either zinc sulphate or dilute sulphuric acid contained in the outer jar.

By this arrangement a supply of copper sulphate is maintained as fast as the copper out of it is deposited on the copper plate.

The internal resistance of a Daniell cell may be anything between 0·75 and 5 ohms, depending on the size of plates and density of the solutions.

It is, however, most frequently about 1·0 or 2·0 ohms in the sizes commonly used at the present day.

The internal resistance can be reduced by having the plates larger and closer together and by diminishing the thickness of the walls of the *porous pot.*

The E.M.F. of all these cells is about 1·1 volt, and is entirely unaffected, as is also the case with any other cell, by the size and distance apart of the plates, or of the rest of the cell, and depends only on the materials used.

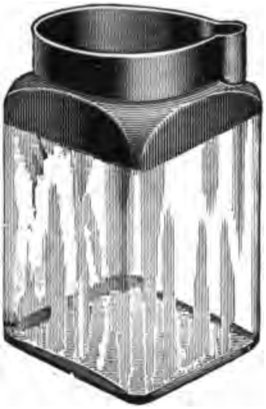
The Daniell cell is, of course, a two-fluid cell in which the copper sulphate acts as the oxidising agent, or depolariser. The hydrogen gas (H), in trying to get across on to the copper plate, attacks the copper-sulphate solution, which has the chemical symbol $CuSO_4$. In so doing it displaces the copper (Cu) and takes its place, forming a new molecule of H_2SO_4, while the copper (Cu) thus displaced is deposited on to the copper plate. In this way no hydrogen gas can get to the copper plate to polarise the cell so long as the copper-sulphate solution is existent; when this is exhausted the cell will begin to polarise.

Leclanché Cell (ordinary bell type).—Of all forms of primary cells probably this one has been the most widely used. Its principal use lies in the production of intermittent currents during long periods such as those required for ringing electric bells, and for such it is much superior to the Daniell cell, but inferior for the purpose of sending steady currents of appreciable strength for any length of time.

It is a *one*-fluid cell, having a solid oxidising or depolarising agent, and consists of an outer glass jar (fig. 6), shaped as shown, the top part of which is dipped into a black compound, which prevents the solution *creeping* from the inside to the outside over the mouth of the jar. A solution of sal ammoniac (ammonium chloride) and water is contained in this outer jar, together with some crystals of the undissolved salt at the bottom.

Into the solution dips an amalgamated, rolled, and almost pure zinc rod (fig. 7), to the top of which is soldered a wire for the purpose of electrically connecting the zinc to the circuit and constituting the $-^{ve}$ terminal or pole of the cell. The $+^{ve}$ pole consists of a carbon plate capped, in the better cells, with a carbon head which forms a seating for the brass terminal. This plate is tightly packed inside a porous pot of unglazed porcelain of high porosity with equal proportions of little pellets (only) of crushed and sifted carbon together with black oxide of manganese, otherwise called manganese peroxide or dioxide, which acts as the oxidising or depolarising agent (fig. 8). A thin layer of pitch then closes the top of the pot, through which pass two short bits of ebonite tube to enable some of the same solution to be poured into the porous pot through one, and air and gas to escape from the other. The function of the pot is not to keep the liquid out but to keep the broken gas carbon, and manganese peroxide in, and both of these latter must be well sifted to remove the dust, so as to expose as much surface of carbon as possible to the solution. Fig. 9 shows a cell complete. While the cell is sending a current, ammonia gas is given off and both water and zinc chloride are formed inside. When the solution turns milky, more sal ammoniac is required; but if the cell fails without,

FIG. 6.

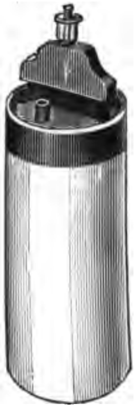


OUTER JAR.

FIG. 7.

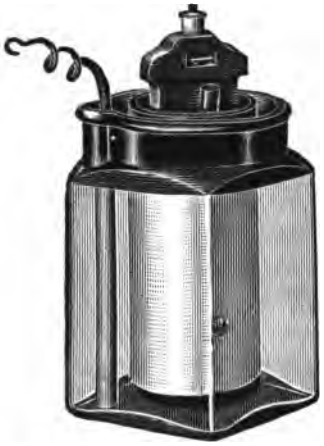
ZINC.

FIG. 8.



CARBON AND POROUS POT.

FIG. 9.



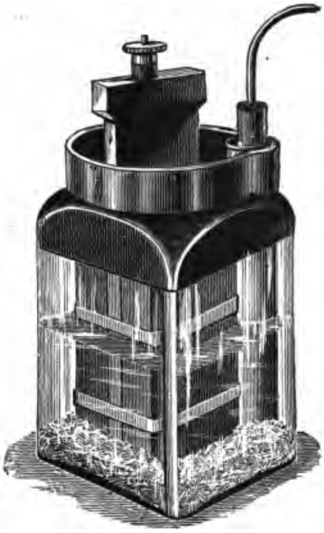
COMPLETE LECLANCHÉ.

then it shows that the depolariser—namely, the peroxide—is in all probability exhausted altogether or is unable rapidly enough to oxidise the gas evolved. This is the case when a strong current is taken from the cell.

The E.M.F. of a Leclanché cell is approximately 1·47 volt, and the internal resistance varies from about 1 to 3 ohms, normally depending on the size of zinc and carbon plates and their distance apart, also on the thickness of the porous pot and density of the solution.

The Agglomerate-block Leclanché Cell is a modification of the form just described, in which the porous pot is usually dispensed with. Fig. 10 shows one method of construction in which the carbon and manganese peroxide are crushed fine, well mixed together and with some binding substance, and then moulded under pressure into blocks, which are finally held against the usual carbon plate by two indiarubber bands. The zinc rod is sometimes held in position by being passed through an eye formed at one part of the band, or by being contained in a small perforated porous pot, as seen in fig. 10, this method avoiding all local action.

FIG. 10.

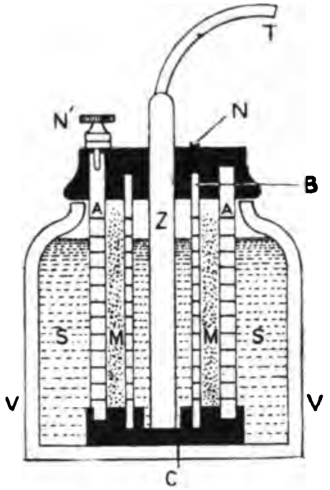


AGGLOMERATE-BLOCK LECLANCHÉ.

The 'Carporous' Cell, devised by Messrs. Lacombe and Leclanché, is another modified form of Leclanché cell. The construction will be understood by reference to figs. 11 and 12, which respectively represent a section and general view. It consists of a perforated cylinder of carbon, A, and one of porous porcelain, B, which rest on a glass foot, C.

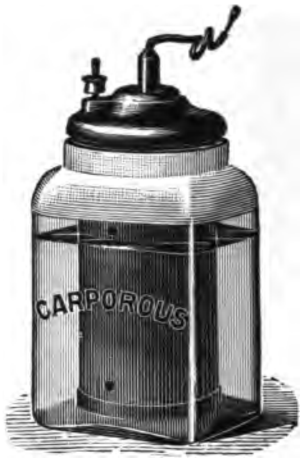
Between these cylinders is packed the mixture of broken carbon and manganese peroxide. The zinc rod, Z, passes down through an insulating cap, N, into the inner porous cylinder, B, and dips into the sal-ammoniac solution. Connection with the carbon cylinder is made through the screw, washer, and nut, N′.

FIG. 11.



SECTION OF 'CARPOROUS' CELL.

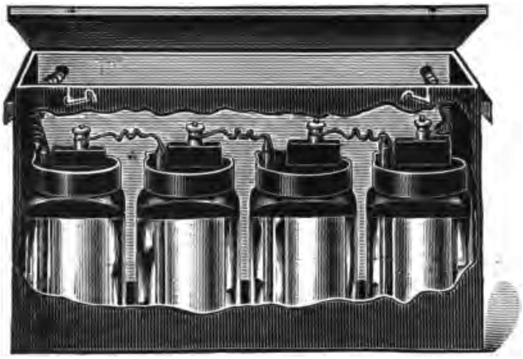
FIG. 12.



'CARPOROUS' CELL.

With the exception of the ordinary form, all these different kinds of Leclanché cells will act and give a current immediately the solution is poured in, but time must be given to the ordinary form to enable the solution to soak through the porous pot before it will work, unless some

FIG. 13.



BATTERY OF LECLANCHÉ CELLS.

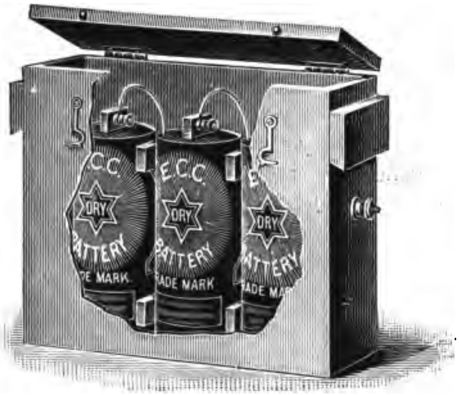
solution is poured into it through the tubes which pass through the pitch sealing. A battery of four ordinary bell Leclanché cells in series is shown in fig. 13.

Dry Cells, so called because they contain no liquid that can spill, but only a jelly-like mass in place of the liquid, are one and all of the Leclanché type. Among the many different forms, the principal ones are the 'Obach,' the 'E.C.C.,' the 'E.S.,' and the 'Century,' or perhaps one should say that these cells are the most widely used in practice.

The construction of them all is much the same, and merely the general features will here be discussed.

The containing vessel or jar consists usually of zinc, which may be surrounded by a cardboard or other suitable covering, or may be painted and form the external case itself. In either case this zinc cylinder or jar forms the $-^{ve}$ pole of the cell, and a wire is soldered to it for making the electrical connection.

FIG. 14.



BATTERY OF 'E.C.C.' DRY CELLS.

The $+^{ve}$ pole consists of a substantial carbon plate in the centre of this zinc cylinder, the two being separated by a mixture of coarsely powdered carbon and manganese peroxide intimately mixed with sal ammoniac, and a small percentage of zinc sulphate, the whole mixed into a stiff paste with a little water and glycerine.

This last named plays no part in the chemical action of the cell, but only serves to bind the materials together. The cells are invariably sealed at the top, usually with melted pitch, two vent-holes being provided for the escape of any gas.

The E.M.F. of all types is about 1·55 volt, and the internal resistance from 0·5 to 3 ohms. For short periods they will give much stronger currents than the ordinary Leclanché cell, and when left on open external circuit, after a discharge, will recuperate to a considerable extent.

As there is nothing in the construction which can spill, these so-called *dry cells* can be used in any position, whether upside-down, on their sides, or otherwise. They are used for a variety of purposes—as, for instance, for mine blast exploders, also by the General Post Office and the National Telephone Company. Fig. 14 shows a box containing three 'E.C.C.' dry cells connected in series and to two terminals, one at each end of the box.

(*b*) Secondary Cells.

The one great objection raised against all types of primary cells is their comparatively rapid polarisation when any but a small current is taken from them, and, though they are eminently suitable for certain kinds of work not requiring more than a very small current—as, for instance, that met with in telegraphy and telephony—they are no use for giving the currents met with in electric lighting and many other kinds of work at the present day. Moreover, the cost of maintaining them is an item which precludes their use for larger currents. Zinc is the fuel used in these chemical electric generators, and it is vastly more expensive than the coal used in dynamic generators.

In the following pages we shall deal with another form of electric cell which is capable of giving out larger currents without polarising or otherwise running down appreciably, except after long periods.

On page 5 it was mentioned that when a continuous current passes through a liquid—as, for instance, water—the latter is decomposed into its constituent parts, the gases oxygen and hydrogen, the latter being evolved at the electrode of the electrolytic cell at which the current leaves, the oxygen from the electrode at which it enters, the cell. In fact, this was mentioned as being one of the properties of an electric current.

In the case of the secondary or storage battery, an electric current generated elsewhere is conducted to an electrolytic cell; if this consists of two strips or plates of ordinary lead, dipping into a dilute solution of sulphuric acid and water, the hydrogen is still given off from the plate at which the current leaves the cell without any chemical action taking place at its surface; but the oxygen developed at the other plate—that by which the current enters the cell—enters into chemical combination with the lead plate at its surface, forming what is known as lead peroxide or lead dioxide, having the chemical symbol PbO_2, and consisting of two molecules of oxygen (O_2) and one of lead (Pb_1).

This chemical combination is accompanied by the plate turning a chocolate or dark-brown colour, the other plate merely remaining the colour of lead.

If, now, this electrolytic cell is disconnected from the source which is sending the current through it, and connected to another circuit not having any E.M.F. in it, a current will flow out of the cell through the circuit *from* the discoloured plate or inside the cell *to* this plate.

Thus, this chocolate-coloured plate is the $+^{ve}$ pole of the cell, and the other, or lead-coloured plate, the $-^{ve}$. Such an appliance is variously termed an electrical *storage cell*, electrical *accumulator*, or *secondary cell*, and two or more of them connected together are called a storage or secondary battery.

The reader, however, is recommended to use the term '*secondary*,' for no electricity whatever is stored or accumulated in the cell when a current is sent through it, just as much passing out as flows in. Chemical changes occur, however, which result in the formation and decomposition of certain substances on charging, while on discharging a reaction or *secondary* change occurs which reduces the substances to the composition which they had before the change was commenced. Hence the propriety of the term *secondary cell.*

A cell constructed in the particular manner indicated would be but little use in practice, as the amount of energy stored up in the comparatively small amount of chemical change is very little.

In order to obtain a much more prolonged secondary action, and a cell that would give out large currents for considerable periods, a larger amount of active material must be exposed to the action of the dilute sulphuric-acid solution.

In other words, the plates must be made more *porous*, so as to offer a greater *effective* surface to the solution, and as much lead peroxide as possible must be formed. This, of course, cannot be realised with plates cut out of ordinary commercial sheet lead, and special means are adopted for the purpose, giving rise to two different types or constructions of secondary cells, known respectively as the *'Planté' or non-pasted type*, and the *'Faure' or pasted type.*

The difference between these types lies entirely in the construction, and in both the ultimate condition when charged up is spongy porous lead for the $-^{ve}$ plate and lead peroxide or dioxide on the $+^{ve}$ plate in a dilute solution of sulphuric acid (oil of vitriol) in water.

Planté Cells—so called after Gaston Planté, who devised the first practical form of secondary cell—consist of almost pure lead plates varying in thickness, in the different makes, from $\frac{1}{4}$ inch to $\frac{5}{8}$ inch. These plates are cut to the required size for making a cell of the desired dimensions, and usually, though not always, pickled—*i.e.*, first inserted in a bath containing some highly oxidising solution, such as a mixture of sulphuric and nitric acids in water or one of sulphuric acid with a certain percentage of the alkaline nitrate of soda, ammonium, or potash. Such solutions rapidly oxidise and eat into the plate, which is taken out after a suitable time has elapsed and washed in water, the plate or its surface is then in the form of spongy or porous lead to quite an appreciable depth (say about 1 mm.).

Several plates are next assembled side by side in an electrolytic bath containing sulphuric acid and water in the proportions of about 1 of concentrated acid to 10 or 12 of pure water. Each plate is separated by about ½ inch from the next, but alternate ones are connected together to form one of the two poles of the cell. A current of electricity is now passed through the cell from some outside source for forty hours or more, and at first nothing is visible except the decolorisation of the plates at which the current enters the bath. Towards the end of the time bubbles of gas (oxygen) are evolved from these same plates, and finally the whole liquid is full of them. A cell in this condition is said to be gasing freely, or (technically) boiling, and is fully charged, the gasing being due to the fact that the plates at which the current enters are incapable of absorbing any more oxygen to form lead peroxide, with the result that this gas is liberated in its nascent form.

The plates on which the peroxide of lead is formed are the $+^{ve}$ plates, and will have assumed a rich dark brown chocolate colour; the other, or $-^{ve}$ plates, being of the slaty grey colour of spongy lead.

In some cases the lead plates are not pickled previously to being 'formed,' as it is termed, by the current in a bath; but in all cases something is done to increase the effective surface of the plates—as, for instance, by building them up of corrugated and perforated thin sheets of lead, or by simply corrugating or grooving an ordinary thick lead plate.

There are several different forms of secondary cells in use at the present day which are wholly or partly constructed on the Planté principle, the process of manufacture being, in some cases, very simple, and in others rather complex.

It will, however, suffice for our purpose to describe one well-known type called the

'D.P.' Secondary Cell.—A diagrammatic view of the plates of this cell is shown in fig. 15, and they consist of a large number of narrow strips, S, of lead, the plate surfaces of which are specially dented, built up one above the other like the leaves of a book.

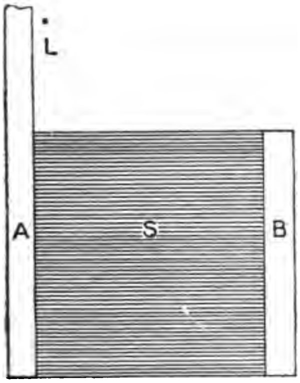
The ends of these strips are lead burned together and to thick leaden side-bars, A and B, of which A is extended to form a lug, L, for burning on to the main cross-bar of lead that connects all the plates of like polarity together to form one terminal of the cell. The strips, S, run horizontally, as indicated in fig. 15, and are there shown edgewise. In a complete cell as many of such plates as are required are placed side by side at suitable equal distances apart, determined by the thickness of the plates of opposite polarity which come in between, and the liquid space as well.

The lugs, L, of all the $+^{ve}$ plates (say) are then burned on to a common crossbar, which forms one terminal of the cell; the same with the $-^{ve}$ plates, which are one more in number than the $+^{ves}$.

These two *sections* ($+^{ve}$ and $-^{ve}$), as they are termed, are next placed in the containing vessel, of course after being 'formed' and interlaced alternately, being mounted and held in position by means of insulating distance pieces and clamping bars.

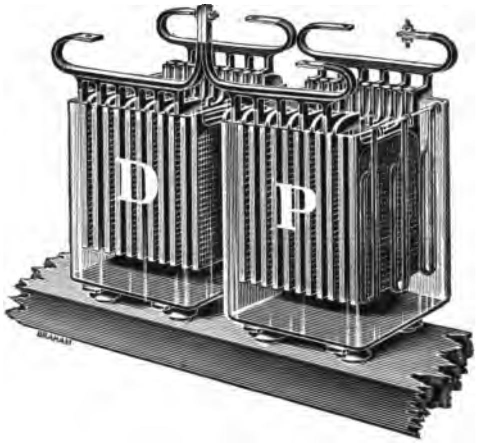
The 'forming' of the plates, as it is termed, is effected by a modification of what is known as Dujardin's process, which consists in making the plates active by a combined oxidising and electro-depositing process in an alkaline bath of nitrates consisting of about 10 parts by weight of water, 2 of sulphuric acid, and 1 of an alkaline nitrate of soda, ammonia, or potash. The charging current through the bath forms nitrate of lead, which the acid converts into lead sulphate, and finally lead peroxide (PbO_2).

FIG. 15.



'D.P.' PLATE.

FIG. 16.



COMPLETE 'D.P.' CELLS.

By reason of the strips not fitting too closely owing to their dented surfaces the plates present a considerable surface, and in a few hours after the 'forming' charge is commenced, lead peroxide, which is formed from the lead surfaces, fills the interstices in the lead plate.

Two of these 'D.P.' cells are shown in fig. 16, mounted and connected in series. The containing vessels are of glass, but in the case of cells having a much larger number of positive and negative plates this vessel is of teak to withstand the weight, and lead lined inside to resist the action of the sulphuric acid. With this method of building all the plates have to be sufficiently well insulated from the lead lining, which would otherwise cause them to be short-circuited.

It should be remembered that, while the 'D.P.' cell just described is one of the most widely used at the present day, the process of its manufacture has been vastly accelerated, as compared with Planté's original method, by the preliminary pickling of the plates.

Such processes, however, for hastening the manufacture of the Planté or non-pasted types of cells are of comparatively recent origin. It occurred to M. Faure, about 1881, to coat the surface of the plates with an easily reducible oxide of lead, called *red lead or minium*, in order to hasten the construction.

On charging such a cell in which both sets of plates are pasted with red lead (of which the chemical symbol is Pb_3O_4) and immersed in dilute sulphuric acid and water, the coating of oxide on the $-^{ve}$ plate is reduced to spongy lead, while that on the $+^{ve}$ is turned into lead peroxide (PbO_2), the whole time taken in bringing about this electrolytic action being from thirty to forty hours.

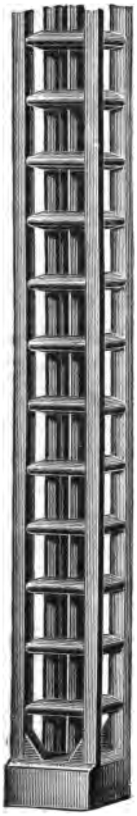
Faure's idea gave, at that time, a great impetus to inventors, who next set to work to find the best means of keeping the paste in position. The fact that it soon fell away directed attention towards a frame or grid for holding it, and into which it was plastered.

Without going into the many forms of grids tried, some with and some without success, we will consider one of the latest and best forms of secondary cells, constructed on the Faure or pasted principle. This cell is the **Headland Secondary Cell**, the construction of which is unique in many ways without being, as is often the case, in the least complicated. The grid consists, as shown in fig. 17, of bars, having square section, and the appearance of a four-sided ladder, the steps of which, so to speak, are braced by four very small rods inside. These bars are cast in any desired length, either in nearly pure lead *or* lead mixed with a small percentage of antimony to make the structure more rigid.

After being cut to the right *length* corresponding to the *height* of plate required, a number of them have their ends burned on to leaden cross-bars, but are separated by narrow air-gaps, as shown in fig. 18 (iv.). In this way a plate or grid of any desired thickness or size is built up, and connection made to it by the two projecting pieces of lead seen on the topmost leaden cross-bar on the left. Each plate is then pasted, those intended for $+^{ves}$ with a thick paste of red lead (minium) and dilute sulphuric acid, and those intended for $-^{ves}$ with litharge or lead monoxide (PbO) and acid; in both cases the spaces between the bars of the plate being cleared out so as to be quite free from paste, and form only air-spaces. Positive and negative plates are then placed side by side alternately, the lead lugs of all the $+^{ves}$ being burned on to a common terminal bar, and similarly for all the $-^{ve}$ plates. The plates are separated by some insulating substance such as glass rods, ebonite strips, or sheets of perforated and corrugated ebonite, &c. This last arrangement is shown in fig. 18 (v.), which represents a traction cell of the Headland type removed from its ebonite containing-case seen to the left.

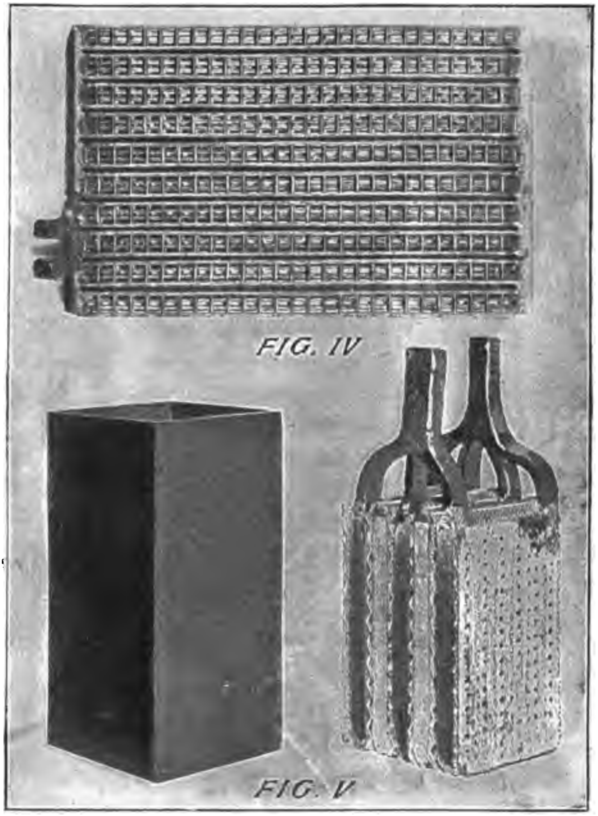
As will be observed, there are three $+^{\mathrm{ves}}$ and four $-^{\mathrm{ves}}$, and in all plate forms of secondary cells there is always one more $-^{\mathrm{ve}}$ than there are $+^{\mathrm{ves}}$. This arises from the fact that unless all the latter are acted on from both sides simultaneously, they tend *to bend*, or, as it is usually termed, '*buckle.*' It is interesting, and indeed important, to compare this Headland form of cell with other types in which the paste is pasted either on to the surface of the grid or through it. These other forms of plates present one continuous surface to the solution, so that in addition to the effective surface being simply equal to the sum of the

FIG. 17.



HEADLAND BAR GRID.

FIG. 18.



HEADLAND PLATE GRID AND TRACTION CELL.

plane areas of the two sides, the material between these surfaces takes no active part in the development of an electric current, and, further, it adds seriously to the weight of the plates, especially when solid, as it sometimes is. This useless weight, though necessary in that type of plate for giving sufficient rigidity to it, is highly objectionable in cells intended for autocar work which have to be carried about on the car. In the case of the Headland cell it is different, there being no solid interior in the grid, which is a light, though strong, structure, and the paste with which it is filled is a good deal lighter than solid lead.

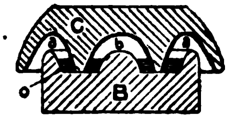
An even greater advantage lies in the enormous increase in the effective surface over that in the usual plate form of cell, for in the Headland cell the action goes on at the surfaces opposite to each other in the plate itself, with the result that the available surface is nearly doubled, consequently the cell gives a much *greater output* than almost any other cell *for the same weight.* In all the different forms of secondary cells precisely the same electro-chemical actions take place—for instance, *on charge* the surface of the $+^{ve}$ plates becomes turned into peroxide of lead (PbO_2), and the $-^{ves}$ into spongy lead, while the acid solution becomes stronger owing to the formation of sulphuric acid; *on discharge* the $-^{ves}$ or spongy lead plates become turned into lead monoxide or litharge (PbO) first of all, and then in a continuous manner into lead sulphate ($PbSO_4$), the surfaces of the $+^{ves}$ are turned into lead sulphate, and the solution gradually loses some of its sulphuric acid, becoming weaker in strength.

During rest, when the cell is sending no current, both plates very slowly *sulphate—i.e.*, a formation of lead sulphate ($PbSO_4$) gradually accumulates on the surfaces of both $+^{ve}$ and $-^{ve}$ plates, causing the cell to *very* slowly run down.

This result is also the case if there is any leakage from the plates down the outside of the vessel to earth.

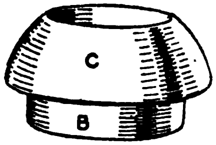
This leakage can be almost entirely prevented by supporting the glass or other containing vessel in a wooden tray, the bottom of which contains a layer of sawdust, and then resting this on what are termed 'mushroom oil insulators,' one of which is shown in side sectional elevation in fig. 19, and in perspective in fig. 20.

FIG. 19.



Section.

FIG. 20.



Complete.

MUSHROOM OIL INSULATOR.

It is made of glass and consists of two parts; the bottom, B, has an annular channel, *o*, on its upper surface, which is filled with a heavy non-evaporative oil, such as resin oil. A projecting rim on the lower surface of the top part, C, dips below the oil and rests on the bottom of this channel. Thus, any leakage from the cell resting on the top of such an insulator, must pass over the top surface, round the outer lip, and across the surface of the oil, where it meets with very great resistance, before it can get to earth.

From what has been said it will be understood that by having several $+^{ve}$ plates connected together, but arranged alternately with similarly connected $-^{ves}$, we obtain the same result as we should from two large plates the area of which is equal to the sum of the areas of the others respectively. At the same time a cell of a more convenient size is obtained.

The current which can be drawn from a secondary cell depends not merely on the type of cell, but on the total area of the $+^{ve}$ sections, and for any particular make it is reckoned as so many ampères per square foot of $+^{ve}$, reckoning both sides of the plate.

In the large variety of makes it varies, according to the construction, from 4 to 20 ampères per square foot of $+^{ve}$ plate. Now, it requires little or no consideration to see that the total amount of electrical energy given out by a secondary cell can never be so large as that put in. Energy being = watts × time in hours—*i.e.*, watt-hours—we have the

$$\text{Energy efficiency} = \frac{\text{watt-hours given out}}{\text{watt-hours put in}},$$

which in actual practice varies from about 60 to 70 per cent. Similarly we have the

$$\text{Quantity efficiency} = \frac{\text{ampère-hours given out}}{\text{ampère-hours put in}},$$

which may be as high as 95 per cent. when the current density (ampères per square foot of $+^{ve}$) is low. The *capacity* of a secondary cell is reckoned respectively in either ampère-hours or watt-hours, either *per lb. of plates* or *per lb. of cell* complete with acid, and in comparing the capacities of cells for portable purposes this latter is the only fair method of doing it.

Planté cells usually have a capacity of about 2 to 3 ampère-hours per lb. of cell complete, while Faure cells have been constructed having 7 watt-hours per lb. of cell complete, which is the figure pertaining to the Headland cell.

Secondary cells are used very extensively at the present day for all kinds of work when a supply of current may be wanted at any moment; their chief use being not merely to act as a stand-by in case of a breakdown of the main running generating plant, but to help this at the heavy loads.

Such cells are expensive in first cost, and should therefore be well attended to, the user being well repaid for good attention to them. Summarising on this point, it may be said that secondary cells must not be discharged or charged regularly at a rate much exceeding that stated by the makers. They should not be discharged below 1·80 volt per cell, otherwise a harder sulphate will form which is highly detrimental to the cell.

An overcharge of short duration will do good—*i.e.*, a continuance of charging for a half to one hour after the cell begins to boil will do no harm to the plates and may do good, though it represents a large proportion of the energy supplied going to waste. Secondary cells should never be left in a discharged condition, but always fully charged if possible, otherwise premature buckling of the plates may occur, with the result that paste, in the case of the Faure type of cell, may drop out, thereby denuding the plates of active material and increasing the risk of internal short circuits through a pellet of paste bridging the space between $+^{ve}$ and $-^{ve}$ plates.

Connecting the terminals by a low resistance, technically called short-circuiting the cell, will probably do more harm than weeks of regular and steady use, if it does not actually ruin the cell altogether.

As the level of the solution falls, through evaporation and spraying during boiling, fresh liquid must be added, whether only water or dilute acid, in such a way as to maintain the density or specific gravity of that in the cell constant, say, when the cell is fully charged.

This density is obtained by means of an hydrometer, or acidometer, as it is variously termed.

Uses of Secondary Cells.—Secondary cells can be put to a large variety of uses where strong, steady currents are required—as, for instance, in electric lighting work when a steady pressure is wanted. The chief use of them is either to supply lamps or electro-motors without any attention, after the running machinery is stopped, or to help the running plant to supply such at periods of heavy or maximum load, when, perhaps, the machinery could not do it alone.

Unlike other sources of power, a secondary battery is capable of responding instantaneously to any demand within limits. To instance an example of its utility, in, say, a direct current electricity supply system of some town during a winter month. The period of maximum load is usually from 4.30 P.M. to about 7.0 P.M. out of the twenty-four hours, and perhaps this may be twice the average load during the day. To supply this maximum at least an equal amount of running machinery must be started up for only two or three hours and then shut down, leaving full steam useless in the boilers.

If a secondary battery, having an output equal to the average demand, was installed, then this would take the extra demand at heavy loads, discharging 'in parallel,' as it is called, with the generating machinery. Thus no extra plant would have to be run.

It should be remembered, however, that the prime cost of such a battery for a given kilo-watt output (for five hours, say) is roughly the same as for steam dynamos and boilers for the same time.

The depreciation is about the same, and need not exceed 5 per cent. per annum for a battery tolerably well looked after. Thus we see that while the first cost is about the same in the two cases, the running cost is less with a battery than if only running machinery is used.

Battery-house.—This should be a *well-ventilated* brick or stone building, having as little metal and wood about it as possible, both being acted on detrimentally by the acid vapours given off during charging. Every cell of the battery should be within easy reach, so that it can be easily inspected and attended to at frequent intervals. Thus the plates must always be kept *covered* with liquid. Any buckled plates must be straightened, and every cell must show about the same terminal voltage **while discharging**. If some do not, they should be carefully inspected to see whether there is any internal short-circuit by $+^{ve}$ and $-^{ve}$ plates being in connection.

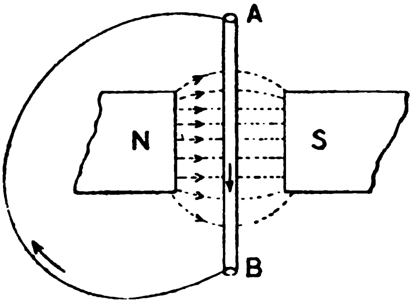
CHAPTER II

DYNAMIC ELECTRICITY

Alternating-current Dynamos and Motors—Two- and Three-phase Generators and Motors—Induction Generators—Direct-current Dynamos and Motors—Transformers, Rotary and Static—The Special Construction of Motors to overcome Dangers of Sparking, &c.—Enclosed and Ventilated Motors.

So far we have only considered the production of electric currents by chemical means, as in the case of primary and secondary cells, but it is possible to obtain such currents by other means. Let N S (fig. 21) represent the north and south poles of a magnetic field, which is shown by the dotted lines, and always taken to flow from the north to the south pole. Let A B be a metallic conductor capable of being moved between N and S so as to cut across the lines of force. If now the conductor is moved away from the observer so as to cut across the lines of magnetic force, an E. M. F. will be *induced* in A B so long as A B is in motion and cutting lines. This will cause a current of electricity to flow from A to B as soon as the ends of A B are joined by a metallic circuit. If A B was the other side of the lines of force, and was moved towards the observer, the induced current would be in the direction from B to A.

FIG. 21.



ELECTRO-MAGNETIC INDUCTION.

We may now mention a most convenient rule, due to Dr. Fleming, for finding the direction of an induced current, and one that should be committed to memory : *With the thumb and first two fingers of the right* *hand forming three directions at right angles to each other, place the thumb in the direction of motion, the first finger in the direction of the line of force, when the induced current will be in the direction of the second finger.* The reader should apply the rule to verify the directions shown in fig. 21, remembering that the thumb will point away from him as A B moves away. The effect thus obtained by the motion of the conductor in the magnetic field is termed electro-magnetic induction, or *dynamic electricity*, and the arrangement is merely one for converting energy in the form of mechanical motion into energy in the form of electric currents. Machines for doing this are termed *dynamos*, or sometimes *generators* simply, and such devices convert mechanical into electrical energy. Now, in practice there are two distinct kinds of current, each of which is used at the present day to a very large extent—one is called *alternating current*, which is a current that flows in an electric circuit to and fro very rapidly, often reversing 200 times per second; the other is called *continuous*, or often *direct current*, which flows in *one direction only* in the circuit. We have, however, touched on this in connection with primary and secondary cells, which are only able to give direct currents.

Later on it will be shown how this kind of current can be produced by the machines above mentioned, but for the present we shall confine ourselves to seeing how alternating current can be produced, as machines for obtaining this were the first to be invented many years ago.

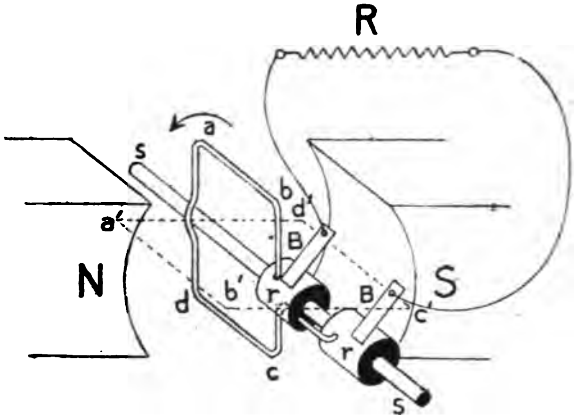
Such are termed alternating-current dynamos or generators, though more often *alternators* simply. Referring to fig. 21, and what was said on page 30, it will be seen that if the conductor, A B, the ends of which are joined to a metallic circuit, is moved backwards and forwards across the magnetic field, induced currents, alternating in direction, will flow in A B; the rate at which this alternating current reverses will depend on the rate at which A B moves across the lines of magnetic field.

Precisely the same effect will be produced if the conductor, A B, is stationary and the field moves to and fro across it. The foregoing is the fundamental principle on which all alternators work, and in practice sometimes the conductors, but now more often the field, move. The kind of motion adopted is of course a circular one, as presenting fewer difficulties than any other.

In order to thoroughly understand the principle and action of the alternator, we will consider the simplest of all forms, in which, for simplicity only, the magnetic field is stationary and the conductor revolves. Let the arrangement take the form shown in fig. 22, in which the conductor is in the form of a wire rectangle, *a b c d*, mounted on a spindle, *s s*, which rotates in suitable bearings (not shown) concentric with the poles, N S, of a magnet. The ends of the rectangle are connected to two metallic rings, *r r*, or pieces of brass or copper tube, which are mounted on and rotate with *s s*, though insulated from it by ebonite bosses, and from one another also. On *r r* press, as they rotate, two springs or brushes, B B, connected to an external circuit, R. Let the position, *a b c d*, of the rectangle be called its 'zero position,' and suppose it to rotate counter-clockwise in the direction of the arrow.

Then, since the lines of magnetic force flow almost horizontally from N to S, *no part* of *a b c d* in or about its 'zero position' will *cut* any of the lines, since *a b* and *c d* are sliding through the lines, and are parallel to them, while *a d* and *b c* are always sliding through the lines for any position of the rectangle; therefore, *no* E.M.F. will be induced or current flow. The maximum number of lines will, however, pass through *a b c d* in this position.

FIG. 22.



SIMPLE ALTERNATOR.

Now, as it turns through such a position as *a'b'c'd'*, *a'b'* and *c'd'* are both cutting perpendicularly across the lines; therefore, applying the right-hand rule on page 30, an induced E.M.F. and current will take place from *a'* to *b'* and from *c'* to *d'*, and these, it will be noticed, coincide in direction round the rectangle, and are a maximum for this position, since the rate of cutting is a maximum. Moreover, in the position *a'b'c'd'* no lines are enclosed, the plane of the rectangle being parallel to their direction.

When *a b* gets round to the position *c d*—*i.e.*, after *a b c d* has turned through 180° or a half-revolution—*a b* and *c d* are again sliding through and not cutting the lines of force. The amount of enclosure is a maximum, and the E.M.F. and current are nothing.

The rectangle now moves into the dotted position in completing the third quarter of the revolution; the limb *a b*, which is now moving upward on the right, has induced in it an E.M.F. and current from front to back, while *c d* in moving down carries a current from back to front.

But this is opposite in sense to what it was in the first half-revolution, and is a maximum when the frame arrives at the end of the third quadrant—*i.e.*, when *a b* gets to 270°; finally, when *a b* arrives at the position it originally started from, after making one complete turn, there is no E.M.F. or current.

We see, therefore, that during the first half-turn the current flows from *a* to *b* and *c* to *d*, while in the second half-turn it flows from *b* to *a* and *d* to *c*. Thus, the E.M.F., and therefore the current, *reverses* its direction *twice* during each complete revolution, or is said to make *one period* per revolution, since the action in any one turn is precisely similar to that in the preceding one at the same position. Stating the action generally for any form of alternator, we have the following taking place simultaneously:

Max. E.M.F. — max. rate of cutting — min. amount of enclosure,

or,

Min. E.M.F. — min. rate of cutting — max. amount of enclosure ;

the points of reversal in all cases occurring at the points of maximum amount of enclosure.

Remembering these rules, it will be easy to find the number of reversals per second in the more complicated and practical forms of alternators met with at the present day.

In fig. 22, if *a b c d* made 1,200 revolutions per minute—*i.e.*, $\frac{1200}{60}$, or 20 revolutions per second—there would be 20 periods per second, since there is one period per revolution.

The number of periods per second is called the '*periodicity*,' or often the '*frequency*' of the alternating current. The method of collecting these currents and distributing them to an external circuit, R, is simplicity itself, and is effected by the brushes, B B, pressing on the continuous metallic rings, *r r*, to which the rotating coil is connected.

It is, of course, very important that the rotating coil should cut as many of the lines of force emanating from the north pole, N, as possible. As, therefore, all these do not flow straight across from N to S, many of them which stray outside are collected and concentrated through the coil by winding it on a laminated soft iron drum or core, which is fixed to *s s* and rotates with it. They then prefer to follow the easier path—viz., through the iron core—to leaking out into the air. In all present-day alternators soft iron is used to direct the lines through the coils, but in some cases the coils are laid on the surface and not wound round the core.

Now, in practice it is essential to produce alternating currents, for lighting lamps and running electro-motors, having a periodicity of at least 40 per second, and often as high as 100.

To obtain such with the simple arrangement of fig. 22 would mean rotating the rectangle, which we must now designate by its technical name of armature, at 6,000 revolutions per minute. This in the larger machines in use now would be impossible, owing to mechanical considerations.

The speed, however, can be kept within safe limits, and yet the desired periodicity be obtained, by increasing the number of pairs of poles—*i.e.*, instead of one pair as in fig. 22, having 10 pairs (20 poles) arranged alternately N.S.N.S.N. round the armature. In this case there would be 10 periods per revolution, and a frequency of 100 periods per second would be given by a speed of 600 revolutions per minute. The practice nowadays is becoming common to standardise all alternating-current circuits in this country and abroad to 50 periods per second, as this is too high to be visibly detected on electric glow lamps, and seems to suit motors better than higher frequencies. There are, indeed, advocates of still lower frequency for power purposes. Twenty-five is now used at Niagara on account of its supposed superiority for motor purposes and transmission, and a frequency of 15 is advocated by some. There are, however, many supply stations using 100 periods per second now.

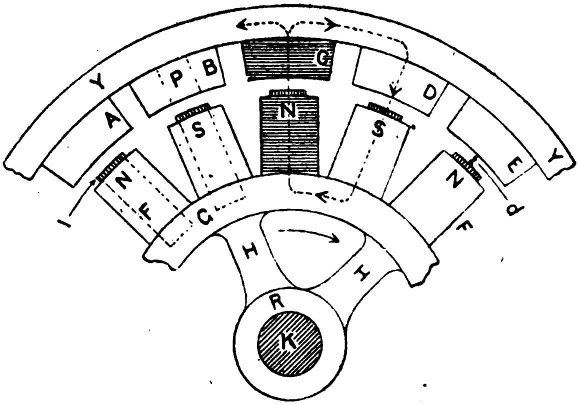
There are three ways of increasing the E.M.F. of an alternator :—

(1) By increasing the strength of the field.
(2) By increasing the speed of rotation of the moving part.
(3) By increasing the number of turns on the armature.

This last method has the disadvantage of increasing the internal resistance of the machine and also what is termed its self-induction. The E.M.F. generated is directly proportional to each of these—*i.e.*, if the speed is doubled, so also is the E.M.F. ; likewise, if the strength of magnetic field and number of armature turns (all round the core) are each doubled together, the E.M.F. would be quadrupled, and so on. (1) and (2), however, can only be applied after the machine is wound, and (1) is by far the most satisfactory method of altering the E.M.F., for in a given alternator (2) cannot be made use of, owing to the alteration of periodicity ensuing from that of speed. In practical alternators the magnetic field is produced by pairs of electro-magnets giving north and south poles alternately round the armature. Since the strength of an electro-magnet varies within limits with the strength of continuous current flowing round its coils, by altering this latter the strength of magnetic field—*i.e.*, number of lines of magnetic force emanating from it—can be altered. These electro-magnets are technically termed the *field magnets* of the machine.

Having discussed the principle of alternating-current generation, we will now describe some well-known type in practical use at the present day to a large extent. Of course, there are many different makes and types, in some of which the armature revolves and field magnets are stationary, in others the reverse is the case, and in a third kind neither revolve, the magnetic field being made to cut the stationary armature conductors by rotating blocks of soft iron fixed to a kind of fly-wheel and termed *inductors*. Hence, this type of alternator is known as the inductor type, and is beginning to be much used at the present day. The principal reason of this is that it is mechanically stronger than the other two kinds, owing, in the first place, to the fact that no portion of any electrical conductor rotates, and, secondly, that the only part that does is the inductor flywheel, which can be made as strong as one pleases. The alternator to be described, and which was referred to above, is that constructed by the Electric Construction Company, of Wolverhampton, and more briefly termed the E.C.C. alternator. In it the field magnets revolve

FIG. 23.



PRINCIPLE OF 'E.C.C.' ALTERNATOR.

inside the ring of armature coils. Fig. 23 indicates the principle on which it is built, but not the actual construction, as space will not permit, nor is it necessary to go into details connected with the shape and ways of fixing the various parts. The part elevational diagram will, however, convey an idea of the method now very generally employed in producing alternating currents of considerable frequency at high pressure. On a mild steel shaft, K, is securely keyed and fixed a kind of flywheel, comprising a mild and highly permeable (magnetically) steel rim, G, of sufficient cross-section to carry the lines of force produced by any one field-magnet coil, and supported or driven by arms or spokes, H, on the boss, R. To G are securely fixed an even number of soft iron cores, I, over which are slipped the field-magnet bobbins, F, wound with cotton-insulated copper wire and secured. These coils are all connected in series, usually in such a way that a current (continuous) passing through them magnetises the iron cores, I, producing alternate polarity, N.S.N.S.N., as shown.

The free ends of the whole series are connected to two continuous copper or brass rings fixed to the shaft, but insulated from it and from one another. Through two fixed strips or brushes pressing on these rings as they rotate with the field-magnet frame and shaft, K, the direct current from a separate dynamo called the *exciter* is led into the field-magnet coils to magnetise them.

The Armature consists of a fixed frame of soft steel, Y Y, into which are fixed as many laminated cores, P, of the best soft iron as there are field-magnet poles or coils. Separately wound armature coils of cotton-covered copper wire (in some cases), A B C D E, are then slipped over these cores and securely fixed in position.

A little consideration will show that these coils must be connected in series alternately right- and left-handedly for the E.M.F.s in all of them to help one another at one and the same instant. If connected otherwise, the E.M.F. induced in one would exactly neutralise that in the next coil, so that no current would flow. Consider now the action that goes on in producing E.M.F. and current as the field magnets revolve, referring, of course, to fig. 23. In the relative positions of the field and armature coils shown, manifestly all the lines of force are flowing through the interior of the turns on the armature coils—*i.e.*, the amount of enclosure is a maximum. Consequently, from what was said on page 33, the rate of cutting of the field by armature conductors at this instant is zero, and therefore the E.M.F. at this instant is also zero. Now, when the field coils have turned through a distance equal to half that between two consecutive armature coils (commonly termed half the pitch), so that each field pole is half way between two consecutive armature coils, the rate of cutting is a maximum, as there is no enclosing, therefore the E.M.F. is a maximum. Further, when the shaded field coil, N, is opposite D, there is no E.M.F. again in any of the armature coils. Similarly, as this field pole, N, moves on from opposite D to E, the E.M.F. induced rises from zero to a maximum (midway between D and E), and then goes down to zero again; but with this difference, that, as N moves between C and D, the induced E.M.F., and therefore the current, is in one direction, while from D to E it flows in the opposite direction. After E the action simply repeats itself in exactly the same manner.

Thus, as the field magnets revolve an alternating current is generated which can be distributed to any circuit connected with the machine.

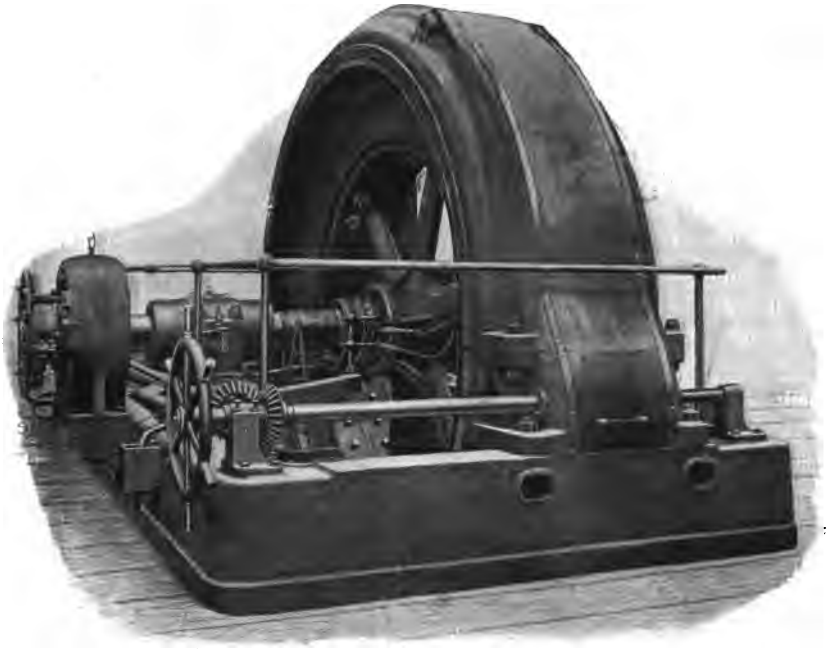
For a given speed, the greater the number of turns of conductor on A B C D E, the greater will be the E.M.F.; while the current which it is safe to draw from the machine will depend on the sufficiency of cross-section of copper in that conductor.

The periodicity per revolution will be equal to the number of pairs of field poles, or, which is the same thing, to the number of pairs of armature coils.

The number of field-magnet poles in alternators at the present day varies with the type and maker, and may be any number up to 60.

The dotted line in fig. 23 represents the approximate mean path of a line of magnetic force through one section of the field magnets and armature. This is unbreakable so long as the field is excited or magnetised.

FIG. 24.



'E.C.C. SINGLE-PHASE ALTERNATOR.

Consequently it revolves as the field-magnet frame revolves, so cutting the conductors in the coils A B C. . . .

The distance, *d*, between iron of field cores, I, and iron of armature cores is made as small as possible so as to reduce the resistance to the passage of the lines of force and diminish the amount of exciting current required.

The power used in exciting the fields has by careful design been reduced at the present day to 1 per cent. or less of the total useful output of the machine, while the efficiency may be as high as 96 per cent. in the case of large machines.

Fig. 24 shows the general appearance of an E.C.C. alternator, the principle of construction of which we have just been considering.

The size of these machines varies enormously, but they are now made up to 40 feet in diameter and in some cases run to upwards of 100 tons in weight.

The E.M.F. may range up to 30,000 volts for very long distance transmissions of electrical power, a common voltage in this country being 2,100 volts, the output ranging up to 2,000 kilowatts or more.

The alternating current which we have, up to the present, been considering is known as a simple, '*mono-phase*,' or '*single-phase*' one—*i.e.*, there is only one current and one circuit, consisting of two conductors side by side, in which it flows.

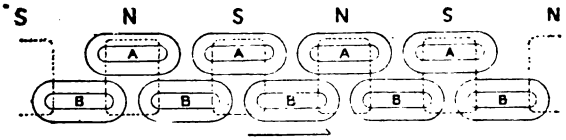
There are, however, what are called multi-phase or poly-phase alternating currents (as they are variously termed), which are not so simple, from the fact that in them one is dealing with more than one current at the same time in a circuit consisting of three or more conductors running side by side.

As such currents are coming into extensive use in this country, but more especially abroad, we will consider how they are produced, transmitted, and employed for useful purposes.

In reality a poly-phase current is a combination of two or more single-phase currents, and in practice two such combinations only are at present employed—namely, two-phase alternating currents and three-phase alternating currents. Let us first consider—

Two-phase Alternating Currents.—These are generated on the same principle as single-phase currents, and if an equal number of similar armature coils be fixed side by side with those shown in fig. 23, but half the angular length of a coil in advance, then if these are connected together like the other set between a second and separate pair of terminals, the arrangement will generate two-phase currents providing both sets are acted on by the rotating field. In fact, single- and two-phase alternators have the same outward appearance, and the only material difference is that in the two-phase machine there are just twice as many armature coils as there are field-magnet poles, while the armature coils are arranged in two distinct sets entirely separate (electrically) from each other. Fig. 25 will

FIG. 25.



PRINCIPLE OF GENERATION OF TWO-PHASE CURRENTS.

make this clearer, and represents part of the field magnets and armature laid out straight. One set, A A A, consists of alternate coils connected in series with each other between two terminals and forms one of the phases.

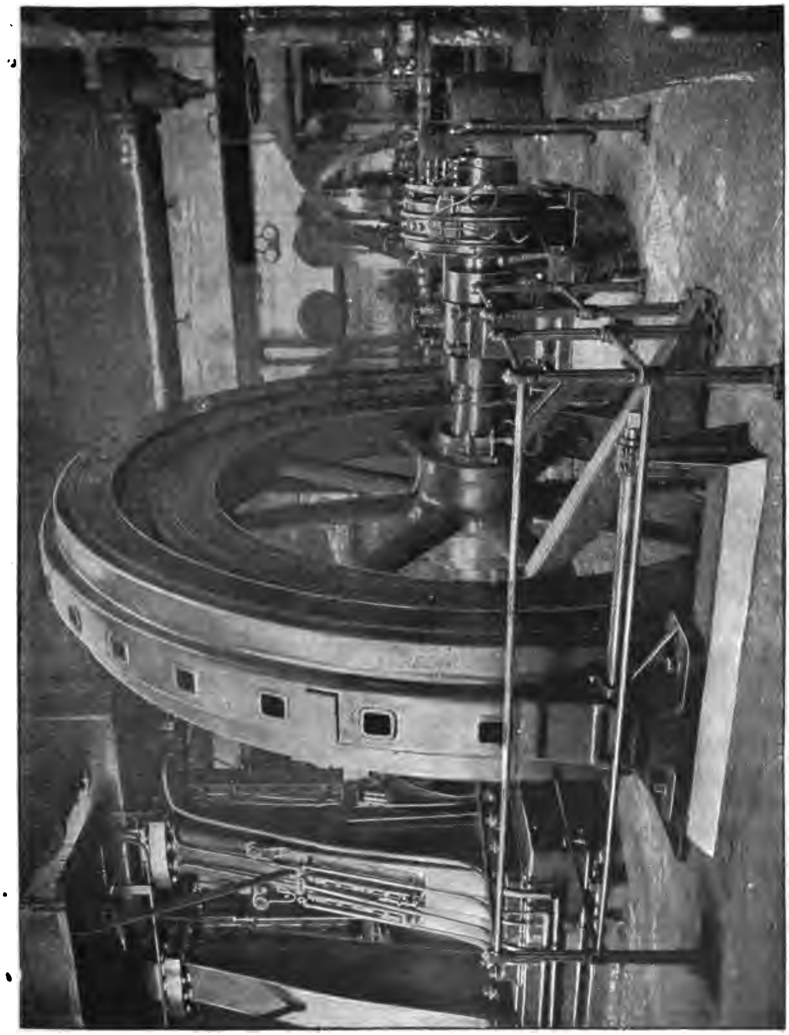


FIG 26.

DIRECT-DRIVEN 'E.C.C.' TWO-PHASE ALTERNATOR.

The other alternate set of coils, B B, is likewise connected in series together between two other terminals and forms the other phase. We therefore see that there are practically two distinct armatures in one, and that each is acted on inductively in turn as the field poles pass them. Succeeding coils of both phases are wound right- and left-handedly as in the single-phase alternator. Now, in the position shown (fig. 25) these field poles (still arranged N.S.N. round the ring and shown dotted) are opposite the set of coils, A A A.

It will therefore be seen that 'set A' is *enclosing* a maximum amount, whereas 'set B' is not enclosing lines at all, but *cutting* them at maximum rate. Hence the E.M.F. of windings or phase A = 0, and that of B is a maximum.

Now, when the field poles have moved on into the position midway between the poles of 'set A'—*i.e.*, just a quarter period—the E.M.F. of phase B = 0 and that of A is a maximum. The same distance further on, the E.M.F. of phase A again = 0 and that of B is a maximum. The E.M.F. continues to alter periodically in a precisely similar manner, but in the opposite direction in the second half period.

Thus two separate single-phase alternating currents are generated which differ in phase—*i.e.*, the times of maxima and minima—by 90°, or one is a maximum when the other is zero, while at any intermediate position each has a certain value. These two E.M.F.s are said to be in 'quadrature,' and we may liken them to the cranks of a compound steam-engine set one 90° in advance of the other.

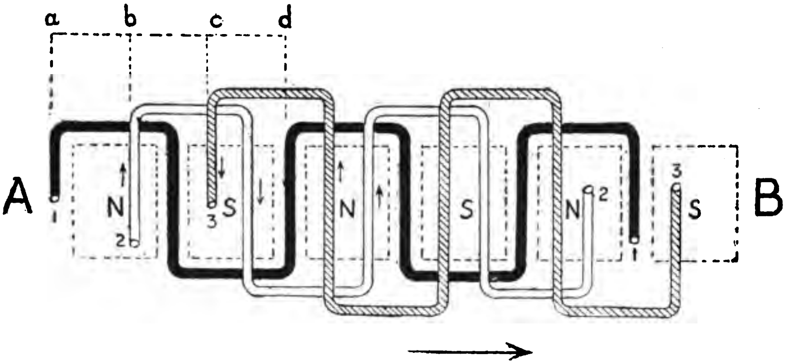
In the system of generation of two-phase current depicted in fig. 25, the periodicity will, of course, be reckoned in exactly the same way as for the single-phase machine, and will be equal to half the number of field poles or armature coils of either phase per revolution. There are, of course, other ways of winding the armature of a two-phase alternator, equally as good as the one described. It will suffice, however, for our purpose to give merely the preceding one. The outward appearance of such a machine is shown in fig. 26.

Three-phase Alternating Currents.—We will now briefly consider how these can be generated; but instead of using the preceding form of construction and winding on the armature, it will be easier to see the principle on which such currents are generated if what is termed a 'wave' winding for the armature be employed. Fig. 27 represents the plan of a portion of such an armature, together with a few field poles (shown dotted), both laid out flat. In the actual construction the field magnets may be internal to the armature and rotate, the latter being stationary, or this may rotate internally with regard to the fixed field. In either case the field poles are alternately N.S.N.S. round the ring, as is usually the case.

The armature consists of three distinct circuits or sets of conductors, 1 1, 2 2, and 3 3, wound in wave form and fixed to the inner periphery of the fixed laminated soft iron shield or frame of the machine, as were the coils A B C to Y in fig. 23. In fig. 27, the conductors cut by the field as it rotates in the direction of the arrow are the vertical bars shown, the horizontal ones completing the 'waves' being merely side connections which in reality do not extend beyond each other, though shown doing so of necessity for clearness.

Now, the distance ad corresponds to a period, or twice the pitch of the field poles, and it will be noticed that each of the three circuits is just $\frac{1}{3}$ of the period, or $\frac{2}{3}$ of the pitch, in advance of the next, or $ab = bc = cd = \frac{1}{3}ad$. At one end, say B, the three circuits have their ends joined together, which junction, as we shall see later, may be connected to earth—*i.e.*, the nearest gas or water main or well-sunk *earth plates*. In the position of the armature shown, no part of circuit 1 1 is in the field; hence the whole circuit is inactive and is generating no E.M.F. Both 2 2 and 3 3 are, however, cutting magnetic lines of force, and will therefore be generating E.M.F.

FIG. 27.



GENERATION OF THREE-PHASE CURRENTS (WAVE WINDING).

Applying the hand-rule on page 30 for finding its direction, and remembering that the field moving from A to B is equivalent to its being still and the conductor moving from B to A, we see that the E.M.F. at this position of the period is in the direction of the arrows. It should also be noticed that the direction in a conductor passing a north pole is opposite to that in a conductor of the same circuit passing a south pole, though by winding in *wave* form they coincide in direction throughout the circuit.

As the rotation proceeds, 1 1 begins to generate E.M.F., while that in 3 3 dies away, and so on, while at certain positions there are E.M.F.s generated in all three circuits. If, now, the three terminals of this three-phase alternator which are connected to the three remaining free ends of 1 1, 2 2, and 3 3 are connected to the necessary three mains, a three-phase alternating current will flow—*i.e.*, currents which attain their maximum strength in each of the three mains successively and periodically, the difference in the times (*i.e.*, difference in phase) of attaining their maximum values being equal to one another and to one-third of the periodic times of each of the three circuits.

The foregoing explanations connected with the generation of single-, two-, and three-phase, or, as they are sometimes called, mono-, bi-, and tri-phase, alternating currents, will probably enable the reader to grasp the principles that underlie their production; but for a more detailed treatment of them reference must be made to standard works dealing with this subject in particular—as, for instance, S. P. Thompson's 'Polyphase Electric Currents' (Spon); G. Kapp's 'Alternators, Motors, and Transformers,' &c.

Direct-current Dynamos.

The three kinds of alternating current which we have been considering are very suitable for the transmission of a large amount of electric power over long distances owing to the facilities they afford of operating at high pressures.

There are, however, some functions which cannot be performed by them, such as the charging of secondary cells and all electrolytic work. For this a uni-directional current, or, as it is usually termed, a *direct* or *continuous* current, referred to on page 31, must be used, and we shall now consider how this is generated.

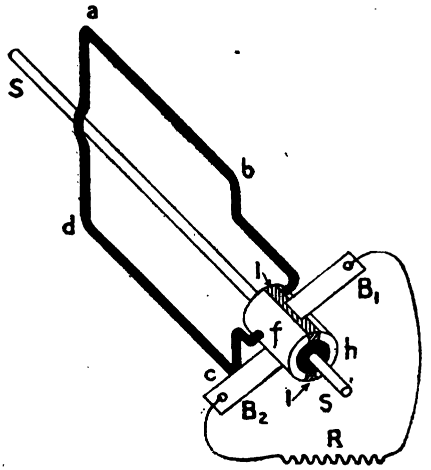
When dealing with the simple form of alternator (fig. 22), we saw that the current in the rotating armature coil, *a b c d*, reversed twice in every revolution when the plane of the coil was perpendicular to the lines of force, and, furthermore, that in this position no E.M.F. was generated in the coil. A little consideration, however, will show that if the ends of the coil could be interchanged with respect to the external circuit or brushes, any such circuit would receive a current which, though fluctuating from zero to a maximum, down to zero again, and so on, would nevertheless be uni-directional in its flow round the external circuit connected to the brushes, that in the rotating coil still being alternating. This interchange is effected by a device known as a *commutator* or *rectifier*, and the current so obtained in the *external circuit* as a commuted-, rectified alternating-, continuous-, or direct-current respectively.

The commutator in its simplest form consists (fig. 28) of a short length of brass or copper tube split axially and mounted on the shaft from which it is insulated; the two parts *f* and *h*, called *segments*, being insulated also from each other by suitable strips of insulation, I I, which make the surface truly cylindrical. This two-part commutator, as it is called, is fixed to the shaft in such a position that the plane of the armature coil includes a line joining the centres of I I.

The two brushes press on the commutator, as the whole rotates, in a line perpendicular to that in which the magnetic field flows and on a diametrical line. Thus, at the instant when the induced E.M.F. in the loop changes its direction, the brushes slide across from one segment to the other, and thus the current, while reversed in the loop, is left flowing in the same direction as before in the external circuit.

This, then, is the principle of commutation and method of obtaining a direct current, which, as we see, originates from an alternating one in the first instance. It has already been observed that the armature conductors must be wound *over* or *on* iron to ensure that as many lines of force as are due to the field magnets pass through the interior of the coil, for then the same number will be cut by it.

FIG. 28.

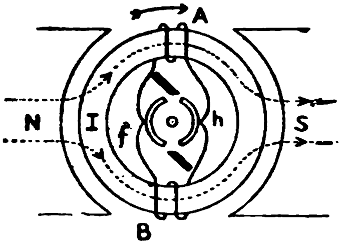


PRINCIPLE OF GENERATION OF DIRECT CURRENTS.

Consequently, in the simple alternator or direct-current dynamo, figs. 22 and 28, the turn or turns, such as *a b c d*, are wound over a well-laminated core of soft iron, consisting of a number of thin circular discs of the best and softest Swedish charcoal iron, threaded over the shaft and keyed to it after having been previously clamped together so as to form a cylindrical *drum* called the *armature core.* The arrangement of core and conductor is then typical of one of the most important kinds of armatures—viz., *drum-wound armatures.* The object in using a laminated core instead of a solid one is to diminish as much as possible induced currents set up in it as it revolves in the magnetic field, for since the discs are lightly insulated by varnish or other means from each other, these induced Eddy or Foucault currents, as they are variously termed, which circulate in paths or planes at right angles to the lines, have no room to flow in and are therefore almost eliminated.

There is, however, another extremely important type of armature in which the coils are wound round a laminated soft iron ring or cylindrical ring core, and which are termed *ring-wound armatures.*

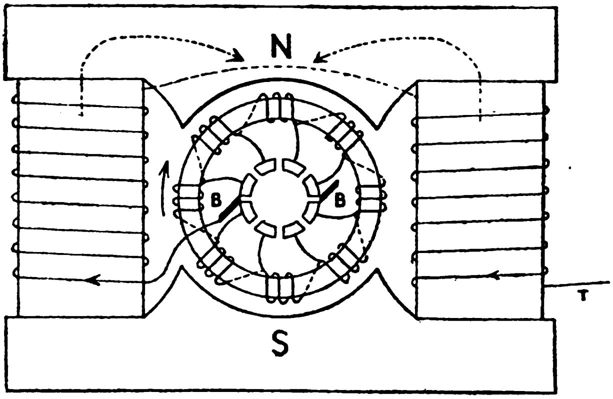
FIG. 29.



PRINCIPLE OF RING WINDING.

Such an arrangement is shown in fig. 29, in which a coil of one or more turns (two shown) is wound on the laminated ring core, I, of iron and connected to the two-part commutator, *f h*. The dotted lines represent the path of the lines of force, which split up into two parts, and if the core is of sufficient section to carry them easily, they are nearly all directed through the coils or are cut by them. Now, it will be evident from the considerations (page 32) that the electro-magnetic action is the same at opposite ends of a diameter at any and every part of the revolution. This fact enables a

FIG. 30.



TWO-POLE DOUBLE MAGNETIC CIRCUIT RING-WOUND DYNAMO.

coil, B, to be wound and connected as shown (fig. 29), which gives the advantage that the internal resistance of the armature (*i.e.*, that between the two brushes) is now only half what it was before owing to the two coils being *in parallel* as it is called. The total E.M.F., however, only equals that produced by one coil if both have an equal number of turns.

The E.M.F., and therefore the current given from a dynamo like that in fig. 29, fluctuates too much to serve any practical purpose. This fluctuation, however, can be diminished as the number of pairs of coils and commutator segments is increased, and we can go on winding pairs of opposite coils, each pair being provided with a two-part commutator. We then come to such an arrangement as that shown in fig. 30, which represents an eight-coil ring-wound armature with its eight-part or segment commutator against which the two brushes, B B, press as it revolves and collect the currents, now much more continuous or less fluctuating in nature.

Now, the brushes, B B, divide the total number of armature conductors into two parallel circuits, which always generate equal E.M.F.s. The actual E.M.F. at the brushes, since there are two parallels, is only equal to tha induced in the conductors on one half of the core, hence we are at once able to obtain a formula expressing this E.M.F. in terms of certain quantities.

Let $C =$ the total number of turns on the periphery of the core.
$N =$ the total number of magnetic lines entering the core.
$n =$ the speed in revolutions per second.

Then the E.M.F. (E) generated is that due to $\frac{C}{2}$ conductors cutting 2 N lines per revolution, since the whole number are cut as any coil, such as A, fig. 29, moves through the first half turn, and again in the second half turn.

Therefore the total *rate of cutting* of lines by conductors is

$$\frac{C}{2} \times 2N \times n = C.N.n.$$

Hence

$$E = \frac{C\,N\,n}{10^8} \text{ volts,}$$

where 10^8 is the number of lines which a conductor must cut per second to produce 1 volt of E.M.F. This last relation is a fundamental one of great importance.

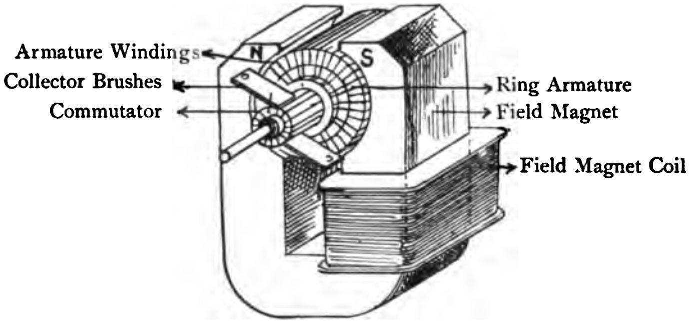
It thus becomes possible to utilise the whole or a portion of the continuous current generated by the armature for exciting the field magnets.

Referring to the last equation, we see that E will be increased by increasing C, N, or n; but there is a practical limit to increasing C and n, the former owing to the serious increases in the armature resistance caused, the latter owing to mechanical considerations and safety.

N, the field, is the best factor to increase, and it will depend on the section and quality of the iron of the field magnets, on the number of turns of exciting coil, and on the strength of exciting current.

There are a great variety of different forms of field magnets in use at the present day, one of which, known as the *double magnetic circuit* type, is shown in fig. 30. Another important form is the *single magnetic circuit* 'over' and 'under' types, of which the former is depicted in fig. 31.

FIG. 31.



ORGANS OF A TWO-POLE DYNAMO MACHINE.

All these are two-pole machines, but direct-current dynamos are made extensively at the present day with more than two poles, in some cases with as many as twelve or sixteen, and are then termed multi-polar generators.

But whatever the form of the magnets, they are always wound with exciting coils in one of three ways, giving rise to what are termed—

Series-wound dynamos,
Shunt-wound dynamos,
Compound-wound dynamos ;

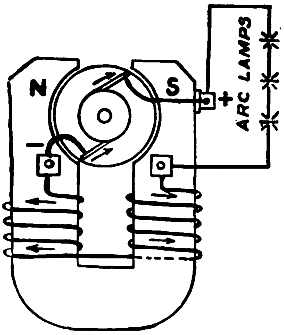
and these we will consider now somewhat in detail.

The Series Dynamo takes its name from the fact that the field magnets are wound with a few turns of thick insulated wire of low resistance, connected in *series* with the armature, and carrying the whole current generated. Fig. 32 shows the arrangement diagrammatically. Machines so wound are most suited to supplying electric glow lamps or arc lamps (shown by the stars) in *series*, at constant current but varying E.M.F. as depicted.

The Shunt Dynamo takes its name from the fact that the magnetising coils are wound with a large number of turns of thin insulated wire, having a large resistance and connected in parallel or as a *shunt* to the armature. They only carry a small fraction of the total current generated by the armature. Fig. 33 shows the arrangement, R S S being appliances in the external circuit which are now connected in parallel with one another and with the armature and shunt coils. In this case the voltage is the same, roughly, on all the appliances in the external circuit, but the total external current equals the sum of all the currents taken by them respectively; hence this kind of machine is suitable for supplying circuits at constant voltage and varying currents—*e.g.*, glow lamps, arc lamps, motors, &c., in parallel.

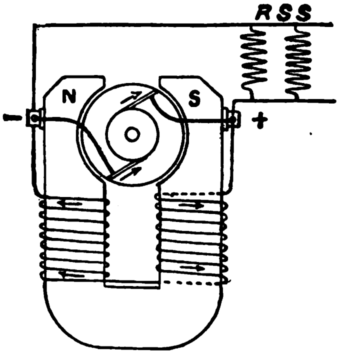
The Compound Dynamo takes its name from the fact that its magnets are wound partly with series, and partly with shunt coils, both of which help each other to magnetise them. Fig. 34 shows the arrangement, the object being to secure *constancy* of terminal voltage as the current taken by the circuit varies.

FIG. 32.



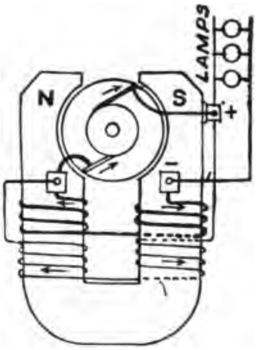
SERIES-WOUND DYNAMO.

FIG. 33.



SHUNT-WOUND DYNAMO.

FIG. 34.



COMPOUND-WOUND DYNAMO.

In the series machine the E.M.F. rises, while in the shunt dynamo it falls slightly, as the current in the circuit rises.

By a suitable combination of these two kinds of field magnets, the E.M.F. is kept constant for all currents; and this fact is highly desirable when supplying glow lamps and other appliances in parallel.

There are two ways of connecting the coils of a compound-wound dynamo, as follows :—

Short shunt, in which the ends of the shunt coils are joined direct to the armature terminals or brushes, and

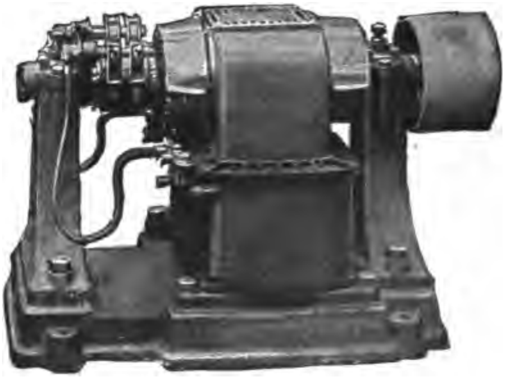
Long shunt, in which they are joined to the extremities of the armature and series coils combined. The short-shunt connections are shown in fig. 34, but the long shunt is the common practice and best for obtaining constancy of E.M.F.

A 5-kilowatt 'Byng-Hawkins' direct-current dynamo, giving an E.M.F. of 220 volts is shown in fig. 35. It is of the over type, with single magnetic circuit.

Fig. 36 shows a six-pole 'Byng-Hawkins' direct-current dynamo coupled direct to a 'Browett & Lindley' enclosed high-speed compound self-lubricating engine, both being on one common bed-plate. These sets are made up to an output of 240 k.w. and upwards by the General Electric Co., London.

We will now deal with a few important general considerations connected with direct-current dynamos. In present-day machines it is usual to have as many brushes as there are poles in the field magnets, equally spaced around the commutator. This in large multipolar machines may have as many as 360 to 400 copper segments with a diameter of 1 foot or more. The brushes are capable of an angular motion on a frame, and when set so that there is no sparking at their points of contact with the commutator for no external current but full voltage, they sometimes require to be given a slight *forward* angular motion, or '*lead*' as it is called, in the direction of motion to collect the current *sparklessly*. In some machines there is no need to touch them from no load to full load, as no sparking occurs. When, however, it does in any machine it should be at once stopped by altering the 'lead' of the brushes to suit, of course while the dynamo is running on its load.

FIG. 35.

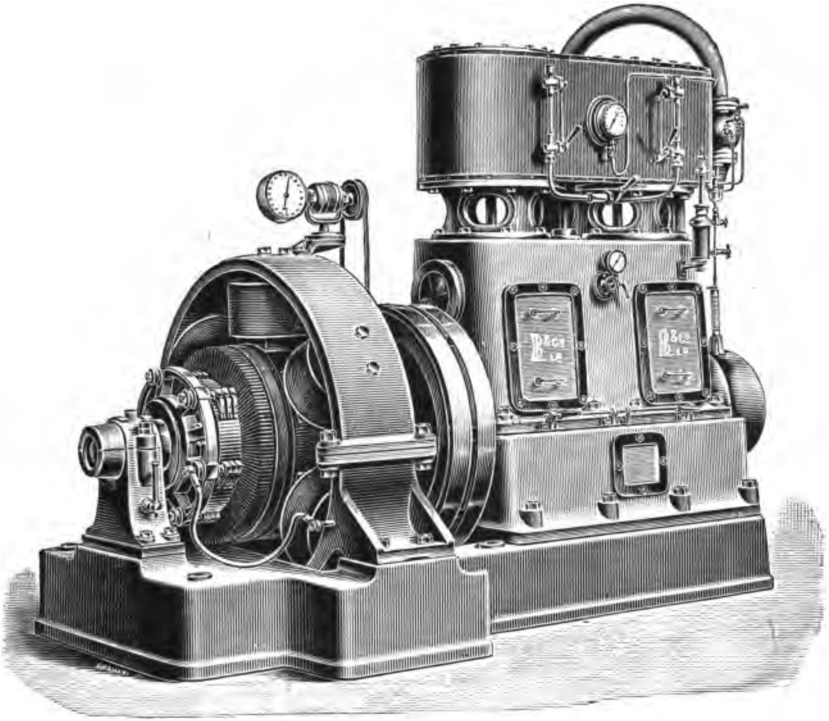


5 K.W. OVER TYPE SINGLE MAGNETIC CIRCUIT DYNAMO.

The commutator should be kept smooth and clean, and if any segment wears flat, it must be at once *remedied* and the cause removed. The cause may be due either to the softness of the copper, or to sparking at this segment, &c.

An electrical generator, whether alternator or direct-current dynamo, should be easily able to do its work, and this to a large extent can be determined before it is installed by running it at full load for six hours, say, and then measuring the temperature of the armature, field-magnet coils, and commutator. This can be done by placing a fairly delicate thermometer, having preferably a thin cylindrical glass bulb, on the surface of either or each of these parts, and covering the bulb and part of the stem with cotton wool to prevent draughts of air affecting it.

FIG. 36.



SIX-POLE DIRECT-COUPLED DYNAMO.

The maximum limit in temperature should not exceed 50° C. for the armature and field coils, and about the same for the brushes and commutator. That of the bearings and other parts should not exceed 40° C. The best makes of machines, however, never attain these values, and, indeed, it is very desirable that they should not.

Electro-Motors.

We must now deal, in some little detail, with that most important class of electrical machine for converting the energy in the form of the electric current flowing through it, into energy in the form of mechanical motion ; in other words, with the *electro-motor*, which is now so widely used.

There are two main classes of electro-motors, viz. :—

Direct-current electro-motors.
Alternating-current electro-motors.

The latter may be subdivided according to whether the motors are to work with *single-*, *two-*, or *three-phase* alternating current, when they are termed *single-phase* or *poly-phase* alternating-current motors.

We will next consider the principle upon which electro-motors act, and will deal first of all with *direct-current electro-motors.* The action of these depends on the following extremely important fundamental principle—namely, *that if two different magnetic fields are under the influence of one another, one being fixed and the other movable, this latter will move so that as many of its own lines of force as possible coincide in direction with those of the fixed field.* This is true no matter how the two fields are generated, whether by simple bar magnets or coils of wire, or whether even both are movable. The force tending to move the material substance producing the movable field increases as one or both fields get stronger.

Turning now to an elementary application of the foregoing principle, we will consider fig. 29. Assuming, of course, that a magnetic field is flowing between N and S, and that a direct current is sent through the two coils in parallel by means of the brushes pressing on the commutator, there will be no force acting on the coils, tending to turn them, if the lines of force they produce *coincide in direction* with those of the fixed field for the position shown. If, however, the current is reversed, the two sets of lines will be in direct opposition, and, providing the fields are strong enough, the coils or armature will make a half-turn, so as to produce maximum coincidence ; but at the end of this half-turn the current is again reversed by the commutator, so that the armature moves through another half-revolution, and so on, a continuous motion being the result.

With only two coils the armature may come to rest at a dead point and not be able to start of its own accord. This, however, can be avoided by increasing the number of coils and commutator segments, when the arrangement shown in fig. 30 will be obtained. When a current is sent through such an armature, each coil tends to set itself with its plane perpendicular to the direction of the fixed field where the coincidence of the two sets of lines is a maximum.

But as soon as a coil gets into this position the current in it reverses, causing it to turn through a further half-revolution. Thus a *uniform* driving force is obtained, and we see that the so-called electro-motor for direct currents is merely a direct-current dynamo used the other way about—*i.e.*, *supplied with current.* It does not follow that all direct-current dynamos run as efficiently when used as motors. They may or may not, but in any case the proper voltage must be supplied to them, which may be found as follows: Run the machine as a generator at the desired speed and note the E.M.F. generated. This must be the pressure of the supply with which the machine must be fed when run as a motor at that speed.

Since there is little or no difference between a motor and a dynamo, what was said a few pages earlier on the latter applies equally well to the former. The armatures are almost always either *ring* or *drum* wound, and the field magnets may be either *series*, *shunt*, or *compound wound.* It is in connection with these latter windings that any particular direct-current motor is spoken of as a 'shunt motor,' or 'series motor.'

Now, it is only while the armature of any motor is stationary that Ohm's Law (page 8) can be applied for finding the current which a given voltage can send through the resistance.

As the armature rotates in the magnetic field an independent action goes on apart from the driving current circulating in the conductors. This is due to the conductors as they rotate cutting the lines of force produced by the fixed field, an E.M.F. being thereby generated which is opposite in direction to that of the supply and opposes it. The term 'Back E.M.F.' has therefore been given to it: its effect is to oppose and diminish the current which the driving E.M.F. is trying to force through the motor. This back E.M.F. has a most important influence on the regulation of electro-motors in general, and the action that occurs is as follows:—

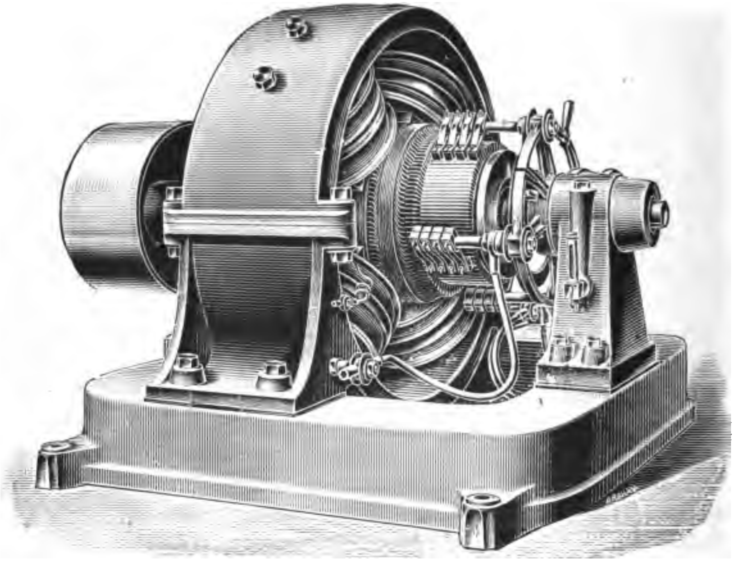
When the current is switched on, and just before the motor starts, it rises at once to its full strength—(the starting rheostat necessary to prevent overheating before the armature begins to revolve is referred to on page 103)—determined solely by the total resistance of the main circuit—*i.e.*, by *Ohm's Law.*

As, however, the armature gets up speed, it generates a back E.M.F. which acts in opposition to the E.M.F. of the supply, and is in direct proportion to the speed. The current is thereby reduced as the speed rises, and if the motor is unloaded the speed will increase until the back E.M.F. nearly equals that of supply, the difference being the pressure requisite for sending the reduced current to overcome the losses and frictions in the motor and circuit. If the motor is started on load it will take a proportionately larger current when in motion than when running 'light' at the same speed, the driving E.M.F. at its terminals also being greater but the back E.M.F. the same, if the speed and field are the same.

Now, it can easily be shown that the '*Torque*' of an electro-motor is *proportional* to the *field strength* and to the *armature current*, and the greater each of these the greater will be the torque. This latter is the moment of the force causing rotation, and equals the total force at the surface of the armature multiplied by radius of armature.

Since, therefore, at starting we get maximum current in an electro-motor, we also get maximum torque, while in a steam-engine, neglecting 'variations of cut-off' and 'wire drawing,' we get equal torque both at starting and at full speed.

FIG. 37.



FOUR-POLE DIRECT-CURRENT MOTOR.

The speed of any motor will be increased by increasing the armature current or diminishing the field current; the former can be accomplished by having a main-circuit rheostat or resistance in series with the armature, when, by diminishing this resistance, an increase of current and speed will result, and in shunt- and compound-wound motors one in series with the field as well, when by increasing the shunt-circuit resistance the shunt current, and therefore the field, is diminished and the speed increased.

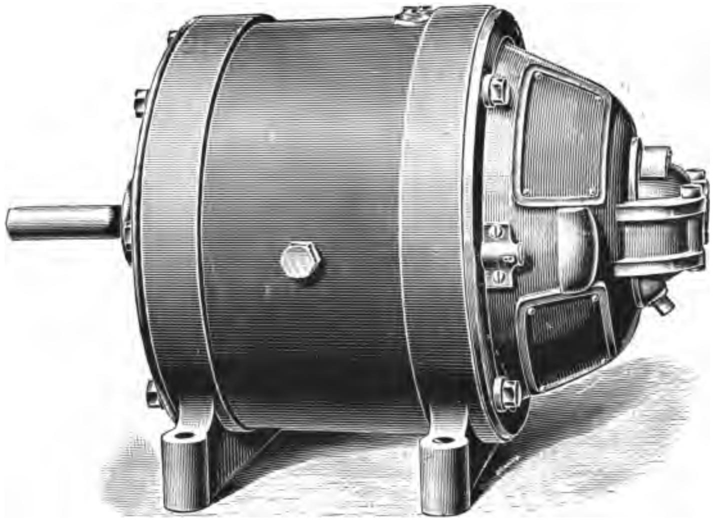
From the foregoing remarks it will be evident that the series motor always exerts maximum torque at starting, while the shunt and compound motors will onl do so providing the field windings are so connected to the circuit that the *shunt* is *fully excited before the armature current is switched on.*

A series motor suddenly relieved of its load begins to race until sufficient resistance is added to the circuit, while shunt and compound motors only slightly increase their speed when the load is removed, the reason being that the back E.M.F. rises rapidly, cutting down the armature current, which in the series motor is also the field current.

Let us now briefly consider the conversion of direct-current dynamos into electro-motors.

A *Series Dynamo, run as a motor,* will run against its brushes unless the terminals of either the armature or field magnets be intercharged with regard to the circuit.

FIG. 38.



VENTILATED ENCLOSED ELECTRO-MOTOR.

A *Shunt Dynamo, run as a motor,* always runs *with* the brushes, for either the armature or shunt currents have reversed in direction, which is equivalent to intercharging the terminals of either.

A *Compound Dynamo* may run *either with* or *against* its brushes according to whether the shunt or the series coils respectively preponderate in strength.

In every case, therefore, it will be seen that in order to run a dynamo as a motor in the same direction—*i.e., with the brushes*—the current in either the armature or the field coils must flow in the opposite direction.

The efficiency of electro-motors should be as high as possible, and in large present-day machines the commercial or net efficiency, which is $= \frac{\text{total power given out}}{\text{total power put in}}$, may be as high as 90 per cent. and over.

The difference (power put in)—(power given out) should, therefore, be as small as possible. It is made up of the losses in the iron and by friction, and also in the copper circuits, and, as we have seen (page 9), if A = armature current and R its resistance, then

$$A^2R = \text{watts lost in armature coils.}$$

Similarly, $a^2r = \frac{E^2}{r}$ = watts lost in shunt coils when a = shunt current, r = shunt resistance, and E = E.M.F at the shunt terminals.

Electro-motors take a great variety of forms. Fig. 37 shows a four-pole direct-current motor of the 'Byng-Hawkins' type, made by the General Electric Company, of London. Fig. 38 shows an *enclosed ventilated* one of the same make, for working in dusty situations.

Alternating-current Electro-Motors.

These may be divided into two classes—namely, (*a*) Single-phase Motors ; (*b*) Poly-phase or Multi-phase Motors. The former may be again subdivided into (1) Synchronous ; (2) Asynchronous or non-synchronous motors.

Any single-phase generator may be used as an alternating-current motor by first starting it, by means of an engine or other motor, up to such a speed that the periodicity of the induced E.M.F. is *equal* to that of the alternating supply and the E.M.F. opposite, and about equal to that of the supply.

Then on switching on the current it will run as a motor without the aid of the machine which started it up, and do mechanical work.

There is, however, one peculiarity about it—namely, that it will run *dead synchronously* with the generator for all loads—*i.e.*, half the speed of the latter will give half the speed on the motor, and so on.

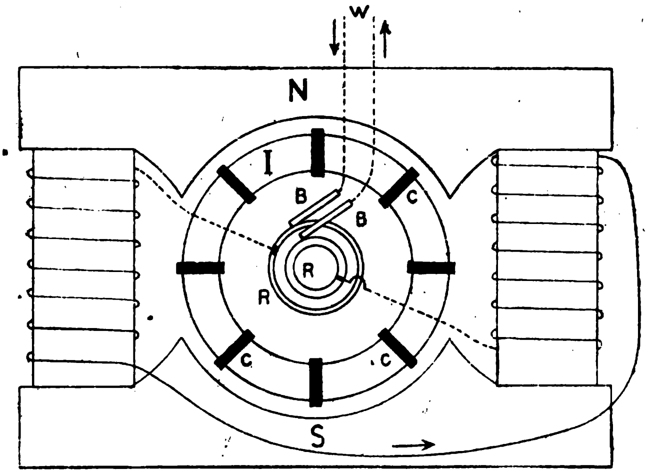
This is called a synchronous single-phase alternating-current motor, and it is *efficient* but *not self-starting*, which is the great disadvantage of it. Another is that the field magnets have to be separately excited by some direct-current source, as they were when it was used as a generator.

The other type is a specially built motor which is *self-starting* but *non-synchronous*, and is usually termed a single-phase *induction motor*. The reason for this is that the principle of action is one of induction in the coils on the moving part, to which there is no electrical connection whatever. There is, therefore, no possibility of sparking, owing to the entire absence of commutator, collecting rings, or brushes. The main disadvantage of these machines is that they are much less efficient, power for power, than direct-current machines, and, moreover, will not start on load without taking an abnormal current for a few minutes.

Poly-phase Motors may be divided into the only two types used in practice—namely, *two-phase* and *three-phase* motors.

Both kinds are *self-starting* (on load or otherwise), *asynchronous*, efficient *induction* motors, and their principle of action will be better understood by reference to the principle on which they work, represented in fig. 39. Let the field magnets of an ordinary bi-polar dynamo or motor, instead of being fixed, be mounted on a shaft capable of rotating in suitable bearings. Also let the ends of the field-coil winding be connected to two copper rings, R R, mounted on the shaft and rotated by it, but insulated therefrom and from one another. A direct current from some source is led into and out of them by two wires (W), connected to two brushes, B B, pressing on R R as they rotate.

FIG. 39.

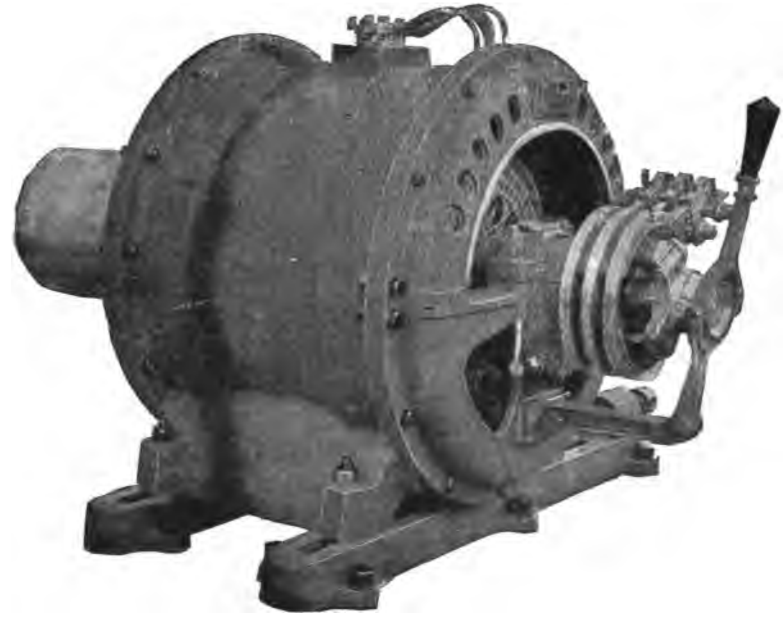


PRINCIPLE OF ALTERNATING-CURRENT MOTOR.

A laminated iron ring, I, mounted on the same shaft and free to rotate on it independently, is wound with coils, C C C, of one or more turns each, short-circuited on themselves, so as to form so many closed coils. If, now, the field magnets are driven mechanically, the field, as it rotates with them also, will cut the coils, C C, the induction of which will set up an E.M.F. and current in each, which will try to follow the field. Hence I will start rotating and will speed up until it catches up the field, when the two will move synchronously together, or nearly so. The rate of cutting of lines of force by the coils, C, is now very small, therefore the E.M.F. and current generated in them are also small.

If, now, load is put on I, its speed will diminish a little, and therefore the rate of cutting, which is proportional to the difference in the speed of the magnets and I, will increase. This increases the induced E.M.F. in C C C, and causes more current to flow in them, thus giving the necessary torque for that load. The function which both two- and three-phase currents perform is to produce this rotating magnetic field without the field magnets rotating or moving at all. The portion of the motor which is wound with coils in a suitable manner to receive the two- or three-phase currents, as the case may be, and which is stationary, is called the *stator*, while the rotating part, corresponding to the ring, I, in fig. 39, is called the *rotor*.

FIG. 40.



THREE-PHASE ELECTRO-MOTOR.

This is the principle of the poly-phase induction motor, which is automatic in taking in just sufficient and no more power than will give the necessary torque to be exerted.

A motor such as this, which is self-starting, entirely automatic in its action, self-lubricating, and which possesses no rubbing contacts or connection to the rotating part whatever, can be left to itself for weeks without any attention ; and, further, all possibility of sparking, which is usually of such moment in mines, is avoided in many of the smaller sizes; for higher powers, slip rings are mounted on the shaft and connected to the rotor coils, which are suitably wound. This is to enable resistance to be inserted in series with the coils to keep down the heavy induced currents at starting, for it will be remembered that the difference in speeds of field and rotor, called the '*slip*,' is greatest at starting, and therefore the induced current also. Fig. 40 shows a three-phase alternating-current motor fitted with these three rotating slip rings connected to the rotor coils. The three brushes pressing on them would be connected to a three-phase rheostat.

Three terminals seen on the top are for clamping the three mains which come from the generator. The commercial efficiency varies from 75 per cent. to 88 per cent. up to 50 h.p., and reaches 94 per cent. for powers over 100 h.p. The rise in temperature above that of the surrounding atmosphere does not exceed 35° C., and the *slip* is 0·5 to 1·5 per cent. of the speed.

The motor illustrated is supplied by the General Electric Company, London, and can be made to work direct on circuits of pressures up to 5,000 volts.

Transformers.

We have already seen (page 9) that when a current of A ampères flows through a circuit of R ohms resistance, the electrical power wasted in it $= A^2R$ watts. Manifestly, then, the loss increases rather rapidly with increase of current which is under the square, but the actual power transmitted will at a pressure V be equal to A V, and this product can be obtained in a great number of ways; for instance, $AV = \frac{1}{2}A \times 2V = \frac{1}{3}A \times 3V = \frac{1}{20}A \times 20V$, and so on. Hence, by increasing V and diminishing A, the same power may be transmitted with very much less loss and at much less cost, as the circuit may have a much smaller cross-section, and therefore cost far less to lay.

As a rule, however, if the transmission be at high pressure, such as 2,000 volts or more, this pressure is far too high for use with many appliances, and it is therefore necessary to reduce it to a workable value, and this is effected by an appliance called a *transformer* or *converter*, or sometimes a *motor-generator*. Of these there are two main classes :—

Direct-current transformers.
Alternating-current transformers.

The former are *all rotary* machines, while the latter comprise both *static* and *rotary* machines. In all cases one and all are essentially transformers of pressure, the section of the coils being such as to be capable of carrying the required current.

The first class of transformer is necessarily of a rotary kind only, comprising either a continuous-current dynamo and motor direct coupled, or an armature wound with two distinct windings, each having a commutator and running in one common field. In either example the motor part is driven by the supply, and in turn drives the dynamo portion to generate current at a different pressure from that of the supply. In the machine with one armature doubly wound in a single field, the ratio of voltages is almost directly proportional to the ratio of armature windings. The efficiency of such machines is low, and if the motor and dynamo portions each had a commercial efficiency of 90 per cent., the whole machine as a transforming device would only have an efficiency of 81 per cent. at full load. Notwithstanding this, it is often economical to employ them in practice. They can and are made to take in power at 2,000 volts, and give out at anything lower desired, such as 100 or 200 volts.

Taking next *alternating-current transformers*, the rotary type is restricted solely for converting continuous to single- or poly-phase alternating currents, or *vice versâ*, and is becoming an important and extensively used appliance at the present day. It consists of an ordinary direct-current dynamo having a *ring-wound armature*, the winding of which is tapped at two or more points, which are electrically connected to two or more copper or brass rings mounted on the shaft, but insulated from it and from one another.

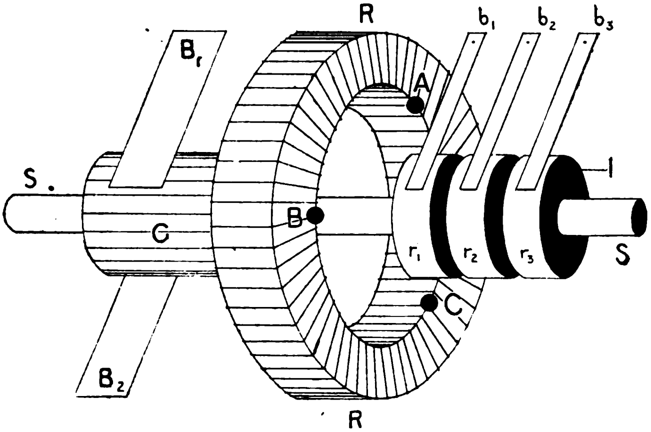
For every pair of poles in the field, two tappings are taken to two slip rings for single-phase currents, four tappings to four rings for two-phase currents, and three tappings to three rings for three-phase currents. The efficiency of these *rotary converters*, as they are called, is high, and they are very useful when poly-phase alternating currents are transmitted, but continuous currents have to be used at the work.

The rotating portion and fixed brushes of a rotary converter, without the field magnets, are represented diagrammatically in fig. 41. S S is the shaft carrying the ordinary direct-current *ring-wound* armature, R R, which is connected to its direct-current multiple-segment commutator, G, at one end, and the three-phase collecting rings, r_1 r_2 r_3, at the other. These rings are insulated from one another, and from the shaft by suitable insulation, I. Fig. 41 actually shows the arrangement for transforming continuous current into three-phase alternating current, or *vice versâ*; the three points, A B C, on the armature winding being equally spaced round it, and connected to the three rings, r_1 r_2 r_3, respectively. If, then, R R rotates in a two-pole field, and direct current is led into and out of R R by the fixed brushes, B_1 B_2, so as to drive the armature as a direct-current motor, then three phase alternating currents will be generated at the fixed brushes, b_1 b_2 b_3.

Conversely, if three-phase currents are led in at these latter, the machine will run as a three-phase motor, and give out direct current at

$B_1 B_2$. Finally, if S S is driven by a belt, the machine will give out both direct current at $B_1 B_2$, and three-phase alternating current from $b_1 b_2 b_3$.

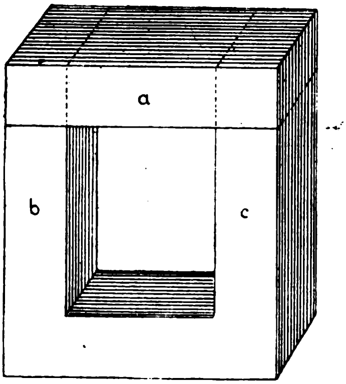
FIG. 41.



PRINCIPLE OF THREE-PHASE CONVERTER.

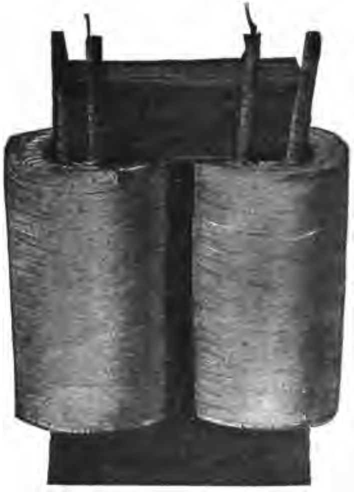
A two-phase converter would have four rings instead of three, which would be connected to four points on R R equally spaced from each other;

FIG. 42.



MAGNETIC CIRCUIT.

FIG. 43.

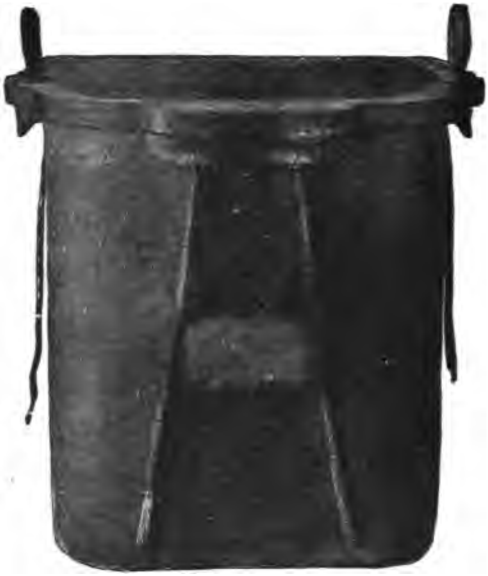


GENERAL VIEW.

while for a single-phase converter there would be two rings only, connected to two points opposite one another on R R.

The most widely used of all transformers is the static type, having no moving parts or contacts, the alternating current in one part performing the function of causing the magnetic field to vary itself, so as to cut the windings in the other part and so generate a greater or less E.M.F., depending on the ratio of the windings on the two parts. A reference to figs. 42 and 43, which show the inside of a 7½-k.w. static transformer supplied by the General Electric Company, London, will make the principle clearer. The core consists of U-shaped stampings, *b c*, out of thin Swedish charcoal iron of the best quality, built up side by side to a sufficient thickness.

Fig. 44.



Transformer in Iron Case.

Two coils, each consisting of two separate windings of double cotton-covered copper wire, are then slipped one over each limb, *b* and *c*, as shown in fig. 43. Cross strips, *a*, are then placed across the ends of *b* and *c*, as shown, thus forming a *closed* iron *magnetic circuit* for the lines to flow in. The two outer coils on the limbs are connected in series to two terminals, and likewise the two inner coils to a second pair of terminals. One coil is then connected across the supply mains, and is called the *primary* ; the other to the lamps or motors, and is called the *secondary* of the transformer In most cases we have

$$\frac{E_1}{E_2} = \frac{N_1}{N_2},$$

where E_1 and E_2 are the primary and secondary E.M.F.s, and N_1 and N_2 are the number of primary and secondary turns. Thus the higher pressure coil will have more turns than the lower pressure coil, and consequently a higher resistance. Fig. 43 shows the construction and the ends of the windings of the inner coils protruding above the coil ends.

When the transformer is to be used in damp places it is enclosed in an iron case with a tight-fitting lid, as shown in fig. 44, the leads going to the primary and secondary passing through insulating stuffing glands or holes in the case.

One extremely important advantage of this static type of transformer is its automatic regulation on constant-pressure primary mains for varying secondary load.

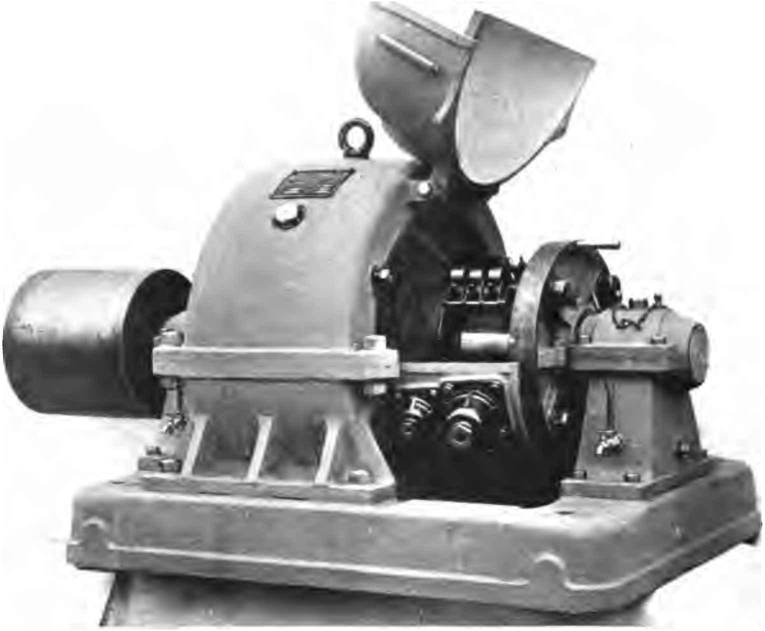
When there is no load on the secondary, the primary takes in just so much power as is required to supply the losses in the iron circuit; at full load it takes in power equal in amount to the total internal losses, plus the secondary output, whereas at half load it only takes in half this amount, and so on. Hence the static transformer is not only entirely automatic in its action, but needs absolutely no attention, being quite inert in itself. By means of such an appliance almost any amount of alternating-current power can be transformed from almost any voltage to any other voltage at an efficiency in the larger types of as much as 96 per cent.

Special Construction of Continuous-current Motors for Use in Coal Mines.

One of the disadvantages urged against the employment of electricity in the mine is the danger of sparks at the brushes igniting fire-damp. There seems to be doubt in some minds as to whether the sparks from the brushes will ignite gas, the reason given being that, owing to the good heat-conducting properties of copper, the sparks would be of very low temperature. There is no doubt, however, that if the brushes get out of position sparking can be set up which will quickly ruin the commutator and readily fire gas if present.

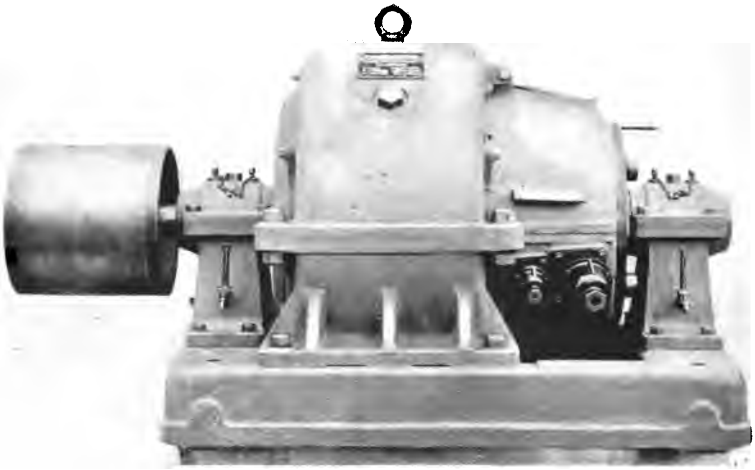
The dangers of the commutator are often referred to as being much less than those of the cable, and, while this may be the case, it is no reason why the lesser danger should be overlooked. The provision of a safe motor for use in the face when coal-cutting where there is a possibility of blowers of gas occurring is of the highest importance. Various designs of motors have been tried with a view to minimising this danger. Many firms employ a completely enclosed and gas-tight motor, with the view to excluding gas from the commutator. Figs. 45 and 46 illustrate an

FIG. 45.



GAS-TIGHT MOTOR (ROSLING & FYNN). COVER OPEN.

FIG. 46.



GAS-TIGHT MOTOR (ROSLING & FYNN). COVER CLOSED.

entirely enclosed motor, the casing round the commutator being hinged, so that it can be lifted up for repairs and attention to the brushes. An entirely enclosed motor is less efficient than one of the same size which is ventilated, owing to the rise in temperature.

The Union Electricity Company, Berlin, who make a great deal of electrical machinery for mines, make an enclosed motor of 80 h.p. guaranteed to work under 100 feet of water; when not under water it is kept cool by compressed air, which is forced into the case; this carries off the heat, and would, of course, exclude gas.

Other makers do not entirely enclose the motor, but leave openings which are protected by wire gauze, the idea being that, should any gas be ignited inside the motor-case, the flame would be cooled below ignition point in passing through the wire gauze. Of course, it must be borne in mind that, as in the safety-lamp, there must be sufficient area of gauze, so that the burning gases do not issue from the motor-case at too great a velocity to be cooled. And until actual tests have been made with a motor in an explosive mixture, absolute security cannot be felt, as an explosion in the motor-case might cause the burning gases to issue so quickly that the gauze would not have time to cool them.

Davis and Stokes Safety Commutator.—This invention successfully obviates danger of sparking at the brushes of a continuous-current dynamo. The construction of the commutator will be understood on reference to fig. 47.

It will be seen that the commutator is made hollow, and the brushes, instead of being in contact with the outside of the commutator, are in contact with the inside. The end of this hollow commutator is closed by a disc, which carries the brushes and is, of course, stationary, and there is a flame-tight joint between the revolving commutator and the stationary disc.

In order to avoid any chance of the disc with its brushes being withdrawn while the machine is running, or of the motor being started before it is properly closed, a locking ring is provided, as shown in the figure. The disc is provided with small windows, by which the working condition of the brushes can be seen, and adjustment of the brushes is made by springs working on the outside of the disc. This arrangement has been thoroughly tested [1] by being made to spark violently in an explosive mixture, but has failed to communicate the flame to the surrounding gas.

Alternating Multi-phase Motors.—In these motors (see page 54) the commutator is dispensed with, and in small sizes, where the motor does not need to start against its load, there is no possibility of sparking.

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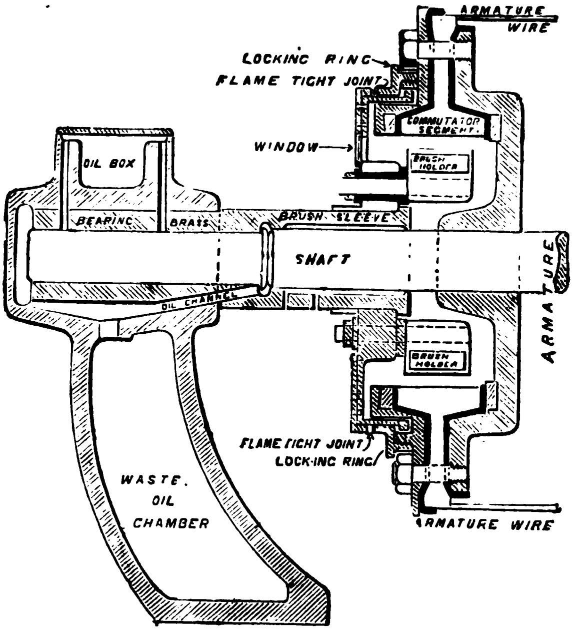
[1] *Transactions Institution of Mining Engineers*, iii. 192.

In larger motors brass slip-rings are usually fitted on which brushes engage, but these are only used at the moment of starting the motor, and when the motor attains its normal speed they are thrown out of gear, so that the sparking, if any, is only momentary. These motors can be completely enclosed.

Fig. 47.



Section of Safety Commutator.

CHAPTER III

DRIVING OF THE DYNAMO

Water Power—Steam Power—High-speed Engines, Direct-driving—Low-speed Engines, Belt-drive—Gas-engines—Oil-engines—Tests of Plants.

THE method of driving the dynamo may be one of the following:—

(1) By the employment of water-turbines.
(2) By the employment of steam-turbines.
(3) By the steam-engine.
(4) By the gas-engine.

Water Power.—The first method depends on a sufficient head of water being always available to drive the turbines, and where this is the case it generally forms the most economical system both in first cost and upkeep. A comparison between steam and water power was recently made,[1] in which the cost of working a 1,000 h.p. steam plant is given as follows:—

	Per h.p. per annum.		
	£	*s.*	*d.*
Interest on capital, depreciation, repairs, &c.	1	7	3
Coal (1·4 lb. per I.H.P. at 16*s.* 0½*d.* per ton)	1	10	10½
Wages (two engineers and two stokers)	0	12	10
Oil, waste, &c.	0	3	4
	£3	14	3½

The lowest cost known to the author (of the article) is £2 8*s.* 6*d.* per h.p. per annum, with coal at 7*s.* 4*d.* per ton.

The steam plant here referred to consists of a vertical compound condensing engine with an average load of 950 h.p., steam pressure 155 lbs. per square inch.

The cost of water-power plant, comprising three wheels, producing a maximum of 510 h.p. and an average of 315 h.p., is given by the same writer as £1 3*s.* 2*d.* per h.p. per annum.

At the Greenside Mine, Patterdale, Westmoreland, where lead ore is worked, the whole of the power required is obtained from water-turbines. The authors are indebted to Mr. W. H. Borlase, mining engineer to the Company, for the following description of the plant.

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[1] *Engineering Magazine*, 1898, xv. 922–927; 'The Comparative Cost of Steam and Water Power.'

Electrical Plant at Greenside Mine, Patterdale.—The source of power, water, is brought from two reservoirs under Helvellyn Mountain, through partly open and covered flumes, for 1¼ mile, following the contour of the hills at an elevation of 1,650 feet above sea level, to the pen-trough at the head of the pipe-line. The pipes are 15 inches in diameter, and convey the water to the power house, situated at 1,250 feet above sea level, giving a fall of 400 feet vertical on 1,200 feet length of pipes, equal to 1 foot in 3. At the bottom of the pipe a Y-piece is attached, and at the ends a vortex turbine and Pelton wheel are respectively fixed, driving two compound-wound continuous-current dynamos, each of 75 kilowatts capacity at 600 volts pressure. The turbine plant has been working since December 1891, including the generator before mentioned, providing power for a 50 h.p. winding motor, compound-wound, one mile inside the mine and two miles from the station. The power is conveyed for the first three-quarters of a mile to the mouth of the level by copper cable of 19/15 B.W.G., on poles and insulators, all cables inside the mine being insulated and lead-covered.

The winding motor lifts the waggons of lead ore stuff, &c., from the various levels from 75 fathoms deep to the day level. The working load averages about 50 cwt.

From this point the current is taken to a motor generator, where the volts are converted from 600 to 250, to work a 14 h.p. electric locomotive which runs the stuff raised by the winding motor through the day level to the washing grates, one and a quarter mile distant. The train load is twelve waggons, varying, of course, in weight, according to the value of stuff, averaging about eighteen tons, exclusive of locomotive, which weighs about two and a half tons. The one and a quarter mile is travelled in about a quarter of an hour, the curves in the level and general conditions not permitting a quicker run. The conductors necessarily are bare, consisting of a No. 10 B.W.G. phosphor-bronze wire.

The Pelton plant was erected in 1897, and is of the same power as the turbine plant, and supplies a 50 h.p. motor for driving an air compressor working inside the mine to supply compressed air rock-drills and pumps, and also an electric motor, driving a Tangye three-throw ram pump forcing water 360 feet high from the 60-fathom level to the day level at one lift. This being a fairly constant load, little supervision is necessary, but there is an electric cut-out in the circuit which immediately acts as soon as one or both of the motors are switched off. So instantaneous and so effective is its action that the volts are not allowed to rise 1½ per cent. before they are again reduced to the normal pressure.

The turbine plant has a varying load, which is easily commanded by a 3-inch by-pass valve, the regulation being quickly done where hydraulic governors have failed. There is only one man kept in the generating station at a time; two shifts a day are worked—viz., from 6 A.M. to 2 P.M., and from 2 P.M. to 10 P.M.

The charges, working and supervision, amount to 1·8*d.* per h.p. per day of sixteen hours in two shifts of eight hours each.

The locomotive has been running nine and a half years, and the charges for that period are equal to ·25*d.* per ton per mile, or ·125*d.* per mile run, as the load is only one way.

The whole of the caging-stations at the several levels, motor-rooms, &c., inside the mine are lighted up with sets of six 100-volt 16-c.p. lamps in series. The crushing-mills, jigger-houses, washing and smelting mills are lighted by a separate dynamo.

Steam Power.—The question of steam generation is too large to enter into in the space at disposal here, besides which it has already been adequately dealt with in several standard works, but mention may be made of one or two details of steam-raising specially applicable to collieries.

Utilisation of Waste Heat from Coke Ovens.—A very important source of economy lies in the generation of steam by means of the gases driven off from coal during the process of its conversion into coke.

There are two chief classes of coke oven: (1) Ovens of the beehive type, in which no attempt is made to take out the by-products, and (2) distilling ovens or closed chambers externally fired, the gases from which are treated by various processes to extract the by-products, and then used to assist in the distilling process, afterwards being taken to the boilers.

It follows, therefore, that a range of beehive ovens will give off waste gas of greater heating power than a similar range of distilling or by-product ovens.

It has been stated[1] that a range of sixty by-product ovens (30 feet long × 6 feet high × 2 feet 6 inches wide) may be supposed to be capable of heating about five Lancashire boilers (8 feet in diameter), the steam pressure being about 120 lbs. per square inch.

Where good water is available for boiler-feeding purposes, water-tube boilers of the Babcock & Wilcox and Stirling type are often used.

Burning of Inferior Fuel.—Another important saving, which is now being effected at many collieries, is the raising of steam from very inferior fuel, which would otherwise not only be wasted but might become a source of danger and annoyance when tipped into a pit-hill, owing to the liability of spontaneous combustion.

The pickings from the coal belts, the settlings from water used in coal-washers, carbonaceous shale, coke dust, &c., can all be utilised in this way.

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[1] *Transactions Inst. M.E.*, xiii. 324.

One means of doing this is by applying forced draught to the ordinary Lancashire boiler, and putting the grate-bars very close together or dispensing with them altogether. This has been done with varying success, one difficulty in the way being that, owing to the fine nature of the fuel, a considerable proportion is blown over the grate into the chimney without being burnt, and, as the combustible matter has a lower specific gravity than the refuse, the most valuable part of the fuel is wasted.

Another drawback to the use of very low-grade fuels in Lancashire boilers lies in the limited grate surface; owing to the lower calorific value of the fuel, a very much greater quantity has to be dealt with in the same time if the steam is to be kept up, and this is a very difficult thing to do.

Meldrum's Refuse Destructor.—The successful solution of the problem seems to have been arrived at by the use of refuse destructors similar to those for town refuse. These have (1) a very large grate area; (2) a combustion chamber which acts as a receptacle for the incombustible dust, which would otherwise tend to choke up the boiler flues.

The construction is very simple, and will be gathered from fig. 48. It consists of a large fire-grate fitted with forced draught, at the back of which is the combustion chamber, from which a flue leads to the boiler.

This arrangement has been adopted at Houghton Main Colliery for burning coke-breeze and coal-pickings.

The plant consists of two cells or furnaces, each having 50 square feet of grate area. The gases are used to fire two Lancashire boilers, each 7 feet 6 inches diameter and 30 feet long. Owing to the forced draught, a small chimney only is required 60 feet high × 4 feet 6 inches diameter. The quantity of steam used in the jets is from 10 to 12 per cent. of the total evaporation.

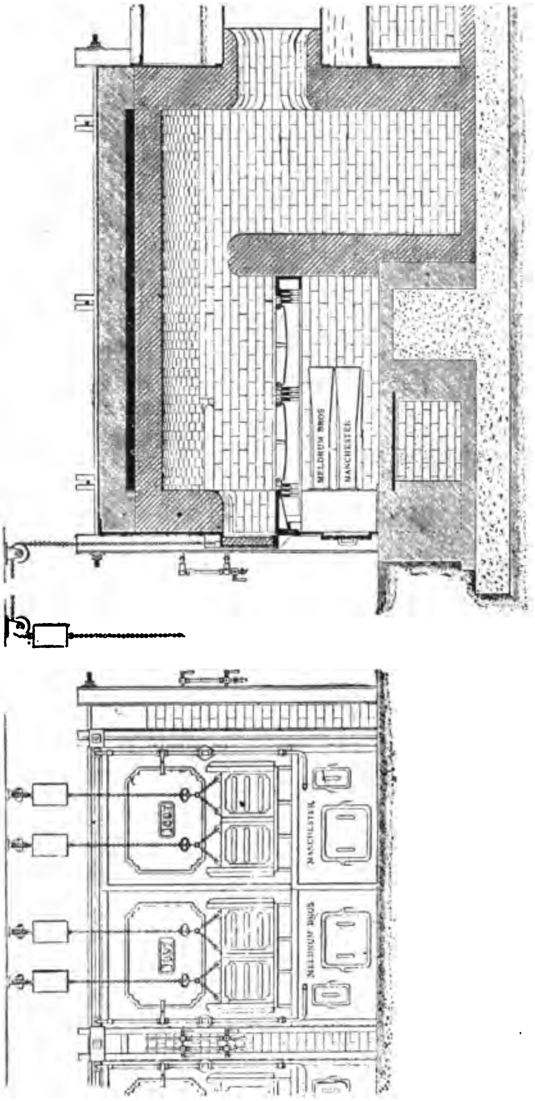
The following particulars of tests on a Meldrum destructor fired with pit refuse from Houghton Main Colliery will be interesting as giving an idea of the performance of the furnaces:—

Grate area	. 63 square feet
Size of boiler	. 8 feet × 30 feet

Date of Test	June 4, 1901	June 4, 1901	June 4, 1091
Class of fuel used . . .	Half coke-dust, half pickings	Pickings	Coke-dust
Weight burnt per hour . .	2,828 lbs.	4,080 lbs.	2,716 lbs.
Weight burnt per sq. ft. grate .	44·8 lbs.	64·7 lbs.	43·1 lbs.
Water evaporated per hour .	7,490 lbs.	11,587 lbs.	6,730 lbs.
Water evaporated per lb. fuel .	2·65 lbs.	2·84 lbs.	2·48 lbs.
Average steam pressure . .	140 lbs.	100 lbs.	100 lbs.
Temperature feed water . .	90° F.	90° F.	90° F.
Percentage of incombustible .	50 per cent.	73 per cent.	38·8 per cent.

High-pressure Steam.—The advantages of using high-pressure steam are—(1) that it reduces the size of steam-pipes and engines; (2) that more work is got out of the same weight of steam. These economies are secured by a very small increase in the amount of fuel used. Thus, the number of British thermal units required to convert 1 lb. of water at 212° to

Fig. 48.



Meldrum Destructor for Burning Inferior Fuel.

steam at 212° (atmospheric pressure) is 966; while to convert it to steam at 100 lbs. per square inch absolute, only needs an additional 35·3 B.T.U.

Steam-turbines.—These are dealt with in Chapter IV.

Steam-engines.—The choice of a suitable steam-engine is governed to a certain extent by the pressure of steam available, and also by the amount of work to be done, and may be one of the following types:—

Single-cylinder horizontal (or vertical) high-speed engine, for direct driving.

Single-cylinder horizontal (or vertical) slow-speed engine, with a rope or belt drive.

Two-cylinder coupled horizontal (or vertical) high-speed engine, for direct driving.

Two-cylinder coupled horizontal slow-speed engine, with a rope or belt drive.

Compound horizontal high-speed engine, for direct driving.

Compound horizontal slow-speed engine, with a rope or belt drive.

Compound vertical high-speed engine, for direct driving.

Triple-expansion vertical high-speed engine, for direct driving.

All these may, if the conditions are suitable, be made condensing.

Single-cylinder Engines.—Where the steam pressure is low, say 50 lbs. to the square inch or under, and the horse-power required is under 50 E.H.P., the most economical engine would be of this type, steam being admitted into the cylinder for one-third of the stroke, and exhausting into a condenser at about atmospheric pressure.

For higher powers coupled engines would be preferred, the reason for this being that, with a single engine, the difference between the maximum twisting moment on the shaft and the minimum twisting moment on the shaft is much greater than in a coupled engine in which the cranks are at right angles, thus the fly-wheel and other moving parts of a coupled engine can be made much lighter.

Compound Engines.—With higher steam pressures, from 60 to 120 lbs. per square inch, greater economy is secured by expanding the steam in two stages, and smoother working by avoiding the extreme differences of pressure in one cylinder. There is abundant experience to prove that, given a sufficiently high initial pressure and sufficient speed of working, a compound or a triple-expansion engine consumes less steam than a simple engine. One of the explanations that have been given is as follows:—

The temperature of steam (saturated, *i.e.*, not superheated) varies directly as the pressure, so that if a single cylinder was used with a very early cut-off the range of temperature in the cylinder would be very great, varying from 327·9° F. (with steam at 100 lbs. per square inch absolute) down to 228° F. (assuming steam exhausting into condenser at 20 lbs. per square inch absolute),[1] and the incoming steam at high temperature coming in contact with the cold cylinder sides would produce a great loss owing to cylinder condensation. By expanding in two or more cylinders this extreme variation is avoided and cylinder condensation largely prevented. Compounding is not good in all circumstances. Superheated steam is a great source of economy, because it does away with cylinder condensation.

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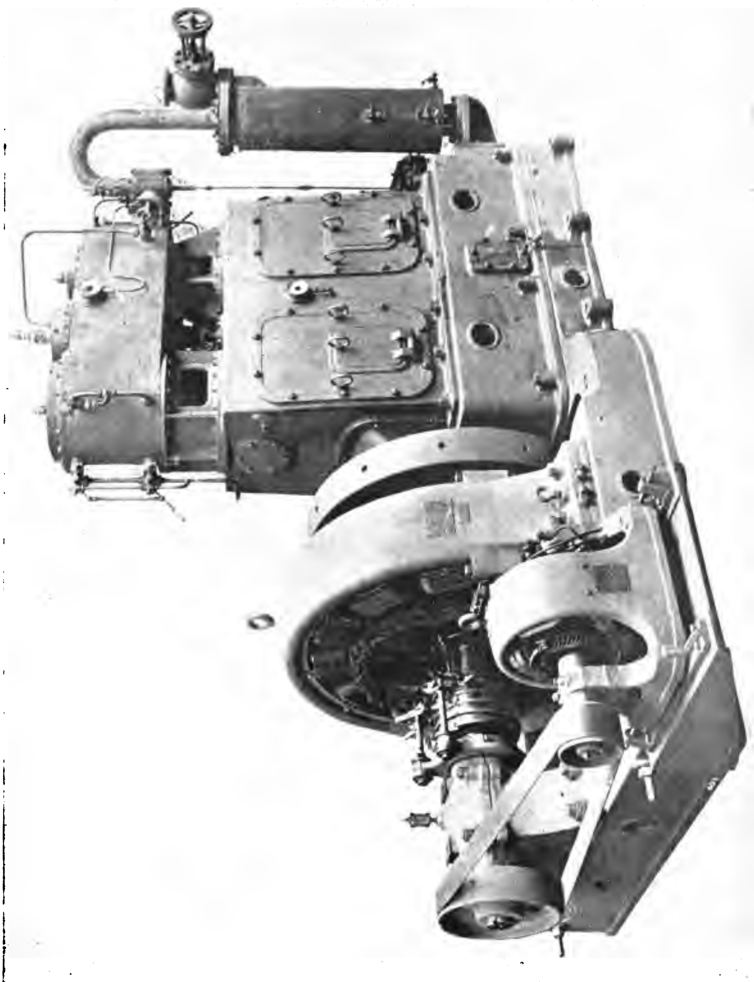
[1] The temperature in the condenser would, of course, be much lower than this, and the temperature of the cylinder during exhaust would, no doubt, nearly correspond to that of the condenser.

FIG. 49.



HIGH-SPEED COMPOUND TWO-CRANK ENGINE WITH THREE-PHASE GENERATOR.

High-speed or Slow-speed Engines.—By using a high-speed horizontal or vertical engine coupled direct to the dynamo shaft without the intervention of gearing, ropes, or belts, as shown in fig. 49, a higher efficiency can be obtained, as there is no loss in transmitting the power from the steam-engine to the dynamo.

An additional advantage possessed by high-speed engines is a saving in space and consequent cheapening of engine-house, foundations, &c.

The disadvantage, however, of coupling direct is that, in case of varying loads, such as are common in colliery practice, when at one time coal-cutters may be thrown on and at another haulage or pumping, great strains are thrown on to the working parts, which in a belt- or rope-driven plant would to a large extent be borne by the ropes.

It is said by the makers of high-speed engines that the losses from cooling in the cylinder are reduced owing to the shorter intervals between the steam admissions. High-speed engines usually revolve from 350 revolutions in the larger size engines of 500 B.H.P. and upwards up to 550 or 600 revolutions in smaller engines.

Vertical or Horizontal Engines.—The chief advantage of a vertical over a horizontal engine is the saving in floor space; and for central stations situated in towns, where the price of land is very high, this becomes a matter of great importance. In colliery installations, however, this rarely carries great weight, although it might be necessary, in putting down a plant in the same engine-house with other engines, to adopt the vertical type, if space was limited and extension impossible.

Vertical engines are not so accessible for oiling, examination, and repairs as horizontal engines, and owing to their having a short stroke they generally run at a higher number of revolutions than horizontal engines.

Gas-engines are frequently used for driving electric generators, and exactly the same considerations that might lead an engineer to adopt gas-engines for other purposes would lead him to adopt them for electric generating. The gas-engine is, however, specially adapted for a central electric plant, because one of the objections to an ordinary gas-engine is difficulty in starting, and a central electric plant would work day and night; therefore the question arises, Does a gas-engine work more economically than a steam-engine? This, however, cannot be discussed here; suffice it to say that in many places gas-engines are used. It has been said by many engineers that gas-engines are not suitable for driving alternating-current generators in parallel, and, indeed, there are several reasons which substantiate this statement. It may, however, be said that some makers of gas-engines are prepared to undertake the erection of a plant with alternating-current generators working in parallel, whilst other makers are not prepared to accept the responsibility. Gas-engines driving continuous-current dynamos are at work in parallel, and there is no reason why any number of gas-engines and continuous-current generators should not work in parallel. The question of periodicity and of running in step does not arise with continuous current. It is only necessary that each generator should produce current at such a voltage that it will pass from the generator into the main. In some places gas-engines are driven with the waste gases from blast-furnaces. There is an enormous amount of power available in the gas which escapes from the top of a blast-furnace which can be more economically used in gas-engines than by being burnt under a steam boiler.

Oil-engines.—The same remarks apply to oil-engines that apply to gas-engines. They are very suitable for driving electric generators, and there are places where oil is the cheapest fuel available. Oil-engines have almost reached a state of perfection, and now use oil with great economy.

Rope or Belt Drive.—The engine may be coupled to the dynamo either by a belt of leather, cotton, indiarubber, &c., or by a number of cotton driving-ropes. The relative merits are a matter of circumstance and convenience. One advantage certainly possessed by a rope drive is that there is less chance of a breakdown, as the ropes would break singly, whilst a belt breaking might cause a serious accident.

Rope- or belt-driving requires a considerable distance between the driver and driven pulleys, as the necessary friction is got not so much by putting tension on, as by the weight of the ropes themselves. For this reason it is usual to make the bottom side the driving side and the top the slack side, as this increases the arc of contact between the rope and the pulleys and gives greater resistance to slipping. The speed of belts and ropes is governed by the tension put on them by centrifugal force, and should not be more than 4,000 or 4,500 feet per minute.

Horse-power Transmitted by Belts.—The table on the next page shows the I.H.P. transmitted by double leather belting running at various speeds.

Horse-power Transmitted by Ropes.—The power which ropes will transmit depends, of course, upon their number and speed, and can be calculated from the following formula :—

Multiply the square of the diameter of rope in inches by the velocity in feet per minute and divide by 300 ; the result will be the power which may safely be transmitted by one rope. The number of ropes should be at least one more than actually required, so as to allow for changing, &c.

Colliery Installations.—The most usual type of engine at a colliery is the horizontal long-stroke engine running at a moderately slow speed and driving the dynamo through the medium of ropes, and such an arrangement, while perhaps not so economical as some which could be adopted, gives good results, and is a type to which the colliery engineer is accustomed. For very large powers, however, it seems probable that direct-acting engines or turbines will in the future be much more largely employed than hitherto. The large direct-driving and reciprocating engine is coupled to a large dynamo and revolves at a moderate number of revolutions per minute, so the difficulties of excessive speed are avoided.

INDICATED H.P. TRANSMITTED BY DOUBLE LEATHER BELTING.

Other speeds or widths in proportion.

Speed of Belt in Feet per Min.	2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.	13 in.	14 in.	15 in.	16 in.	17 in.	18 in.	19 in.	20 in.	21 in.	22 in.	23 in.	24 in.	25 in.	26 in.	27 in.	28 in.	29 in.	30 in.
400	2·4	3·6	4·8	6·0	7·2	8·4	9·6	10·8	12·0	13·2	14·4	15·6	16·8	18·0	19·2	20·4	21·6	22·8	24·0	25·2	26·4	27·6	28·8	30·0	31·2	32·4	33·6	34·8	36·0
450	2·7	4·0	5·4	6·7	8·1	9·5	10·8	12·2	13·5	14·8	16·2	17·5	18·9	20·2	21·6	22·9	24·3	25·6	27·0	28·4	29·7	31·1	32·4	33·7	35·1	36·4	37·8	39·1	40·5
500	3·0	4·5	6·0	7·5	9·0	10·0	12·0	13·5	15·0	16·5	18·0	19·5	21·0	22·5	24·0	25·5	27·0	28·5	30·0	31·5	33·0	34·5	36·0	37·5	39·0	40·5	42·0	43·5	45·0
600	3·6	5·4	7·2	9·0	10·8	12·7	14·4	16·2	18·0	20·0	21·6	23·6	25·4	27·0	28·8	30·9	32·4	34·5	36·0	38·1	40·0	41·4	43·2	45·0	47·2	48·6	50·8	52·2	54·0
800	4·8	7·2	9·6	12·0	14·4	16·8	19·2	21·6	24·0	26·4	28·8	31·2	33·6	36·0	38·4	40·8	43·2	45·6	48·0	50·4	52·8	55·2	57·6	60·0	62·4	64·8	67·2	69·6	72·0
1,000	6·0	9·0	12·0	15·0	18·0	21·2	24·0	27·0	30·0	33·0	36·0	39·0	42·0	45·0	48·0	51·0	54·0	57·0	60·0	63·0	66·0	69·0	72·0	75·0	78·0	81·0	84·0	87·0	90·0
1,200	7·2	10·8	14·4	18·0	21·6	25·2	28·8	32·4	36·0	40·0	43·2	47·2	50·8	54·0	57·6	61·8	64·8	69·0	72·0	76·2	80·0	82·8	86·4	90·0	94·4	97·2	101·6	104·4	108·0
1,400	8·4	12·6	16·8	21·0	25·2	29·4	33·6	37·8	42·0	46·2	50·4	54·6	58·8	63·0	67·2	71·4	75·6	79·8	84·0	88·2	92·4	96·6	100·8	105·0	109·2	113·4	117·6	121·8	126·0
1,600	9·6	14·5	19·2	24·1	29·0	33·8	38·4	43·5	48·2	53·0	58·0	62·8	67·6	72·3	76·8	81·6	87·0	91·8	96·4	101·4	106·0	110·8	116·0	120·5	125·6	130·5	135·2	140·0	145·0
1,800	10·9	16·3	21·8	27·2	32·7	38·1	43·6	48·9	54·5	60·0	65·4	70·8	76·2	81·5	87·2	92·6	97·8	103·2	109·0	114·3	120·0	125·4	130·8	136·0	141·6	147·0	152·4	157·8	163·0
2,000	12·0	18·0	24·0	30·0	36·0	42·4	48·0	54·0	60·0	66·0	72·0	78·0	84·0	90·0	96·0	102·4	108·0	114·0	120·0	126·8	132·0	138·0	144·0	150·0	156·0	162·0	168·0	174·0	180·0
2,200	13·3	20·0	26·6	33·5	40·0	46·6	53·2	60·0	67·0	73·6	80·0	86·6	93·2	100·5	106·4	113·0	120·0	126·6	133·0	139·8	147·2	153·8	160·0	167·5	173·2	179·8	186·4	193·0	200·0
2,400	14·4	21·6	28·8	36·0	43·2	50·4	57·6	64·8	72·0	80·0	86·4	94·4	101·0	108·0	115·2	122·6	129·6	136·8	144·0	152·4	158·4	165·6	172·8	180·0	188·0	194·4	201·6	208·8	216·0
2,600	15·7	23·6	31·4	39·3	47·2	55·0	62·8	70·8	78·6	86·4	94·4	102·2	110·0	117·9	125·6	133·4	141·6	149·4	157·2	165·0	172·8	180·6	188·6	196·4	204·2	212·0	220·0	227·8	235·6
2,800	16·8	25·2	33·6	42·0	50·4	58·8	67·2	75·6	84·0	92·4	100·8	109·2	117·6	126·0	134·4	142·8	151·2	159·6	168·0	176·4	184·8	193·2	201·6	210·0	218·4	226·8	235·2	243·6	252·0
3,000	18·0	27·0	36·0	45·0	54·0	63·6	72·0	81·0	90·0	99·0	108·0	117·0	126·0	135·0	144·0	153·6	162·0	171·0	180·0	189·0	198·0	207·0	216·0	225·0	234·0	243·0	252·0	261·0	270·0
3,200	19·2	29·0	38·4	48·2	58·0	67·6	76·8	87·0	96·4	106·0	116·0	125·6	135·2	144·0	154·0	164·2	174·0	183·6	193·2	202·8	212·0	222·0	231·6	241·0	250·6	260·2	270·0	279·4	288·0
3,400	20·6	30·9	41·2	51·5	61·8	72·1	82·4	92·7	103·0	113·3	123·6	133·9	144·2	154·5	164·8	175·1	185·4	195·7	206·0	216·3	226·6	236·9	247·2	257·5	267·8	278·1	288·4	298·7	309·0
3,600	21·8	32·6	43·6	54·4	65·4	76·2	87·2	97·8	109·0	120·0	130·8	141·6	152·4	163·0	174·4	185·2	195·6	206·4	217·2	228·0	238·8	249·6	260·4	271·2	282·0	292·8	303·6	314·4	326·0
3,800	22·9	34·3	45·8	57·2	68·7	80·5	91·6	103·4	114·5	126·0	137·4	148·8	160·2	171·5	183·0	195·0	205·8	217·2	229·0	241·1	252·2	264·0	274·8	286·0	297·6	309·0	320·4	331·8	343·0
4,000	24·0	36·0	48·0	60·0	72·0	84·8	96·0	108·0	120·0	132·0	144·0	156·0	168·0	180·0	192·0	204·8	216·0	228·0	240·0	252·0	264·0	276·0	288·0	300·0	312·0	324·0	336·0	348·0	360·0

For Single Leather Belts deduct *one-third* from above amount.

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Economical Generation of Electric Power.—The question of the relative efficiency of the various systems of transmitting power will be gone into at some length in Chapter VIII., but the economical generation of that power is of great importance and deserving of equal consideration.

The question of colliery consumption has received great attention at the hands of colliery managers and mining engineers in recent years, and modern collieries have been equipped with the most economical of steam raising and using plant.

In a recent paper in the 'Transactions of the Institution of Mining Engineers,'[1] Mr. J. A. Longden gives the following particulars of colliery consumption, which will be useful for purposes of comparison:—

Colliery	Annual Output	Coal Consumed		Depth of Pits
	Tons	Tons	Per cent.	Feet
No. 1	200,000	6,400	3·2	390
No. 2	300,000	9,000	3·0	630
No. 3	200,000	7,000	3·5	780
No. 4	200,000	10,000	5·0	450
No. 5	100,000	10,000	10·0	480
No. 6	300,000	22,500	7·5	600
No. 7	400,000	21,200	5·3	1,500
No. 8	150,000	10,500	7·0	2,000

No. 5 pit is heavily watered in proportion to its output, raising 30,000 gallons per hour from the full depth of the pit. No. 6 pit has also a good deal of water, raising 15,000 gallons per hour. The economies effected in steam generation are by the use of high-pressure steam up to 160 lbs. per square inch, economisers to heat the feed water, employment of Lancashire boilers, use of mechanical stokers and forced draught, efficient covering of boilers and steam pipes. The economies effected in the use of steam are by a high degree of expansion, compound and triple expansion engines, condensers, super-heating.

Mechanical Efficiency of Plant.—With an electrical plant which is supplied with steam from independent boilers, it is an easy matter to arrive at the consumption of steam and fuel per E.H.P. per hour. The voltage and ampères at the terminals of the dynamo are measured,[2] then $\text{E.H.P.} = \frac{\text{volts} \times \text{ampères}}{746}$, and by measuring the quantity of feed water supplied to the boiler to keep a constant height of water as seen in the gauge-glass, and by weighing the fuel used, the result is arrived at by a simple-division sum.

Supposing the engine to be a compound condensing horizontal engine driving the dynamo through ropes, the steam consumption per I.H.P. (in a good engine) should be about 15 to 25 lbs. per hour ; if the steam consumption per E.H.P., as found above, comes to a high figure, such as 50 lbs. per hour, it shows a great loss, and the object of the engineer should be to discover where this loss takes place.

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[1] Vol. xvi., 1898–9, p. 366.

[2] If alternating currents are used a watt-meter is required to measure the electric power.

The Steam-engine Indicator.—The indicated horse-power of the engine can be found by means of the indicator, which gives diagrams of the work being done during a stroke. Diagrams are taken both at the back and front ends of the cylinder at frequent intervals during the test, the revolutions of the engine being noted by a counter.

The average pressure during the stroke is found by dividing the area of the indicator diagram by its length, and multiplying by the scale of the spring. Then

$$\text{I.H.P.} = \frac{2\,\text{PLAN}}{33{,}000},$$

where P = the mean effective pressure in lbs. per square inch.
L = the length of the stroke in feet.
A = the area of the cylinder in square inches.
N = the number of revolutions per minute.

In a compound engine, of course, both high- and low-pressure cylinders are indicated, the total I.H.P. being the sum of the I.H.P. of each cylinder.

We are now in a position to find the steam consumption per I.H.P. per hour, and it may be that the loss is chiefly taking place in the steam-engine. A high steam consumption may be caused by defective or badly set valves, leaky pistons, &c., or it may be due to condensation or leakages in the steam-pipes from the boiler.

The loss due to condensation or priming should be found by collecting the condensed steam from the pipes. Leakages in the pipes would be self-evident.

A careful study of the indicator diagram will give a great deal of information as to the setting of valves, &c.

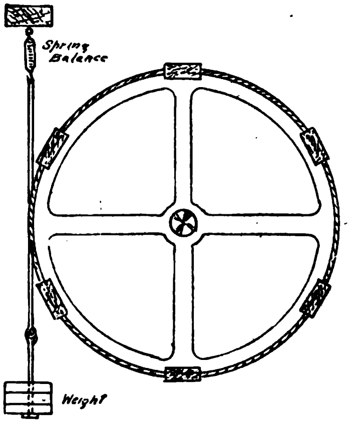
Brake Horse-power.—The brake horse-power represents the power available for useful work obtained by deducting from the I.H.P. the power necessary to drive the engine without its load. By means of a friction brake on the fly-wheel or driving-wheel of the engine the B.H.P. can be measured. The details and arrangement of a friction brake (or absorption dynamometer) will be seen in fig. 50, the B.H.P. being calculated as follows :—

$$\text{B.H.P.} = \frac{2\pi r \text{N}(\text{W} - w)}{33{,}000},$$

where r is the radius in feet of the fly-wheel or pulley and rope together.
N is the number of revolutions per minute.
W is the weight hung on the brake in lbs.
w is the reading of the spring balance in lbs.
$\pi = 3{\cdot}1416$, or approximately $\frac{22}{7}$.

If the B.H.P. is abnormally low when compared with the I.H.P., it shows that the friction of the engine is too great, which may be due to inefficient lubrication or improper design or adjustment of working parts, such as stuffing-boxes, guides, bearings, &c.

FIG. 50.



FRICTION BRAKE OR DYNAMOMETER.

Full Load and Light Load.—The plant works most economically at full load, because then the proportion of work done in overcoming the friction of the engine is a much smaller percentage of the total power produced. The steam consumption per I.H.P. is also much greater at low loads, the losses in the cylinder, leakages of valves, pistons, &c., being about the same as when running at high loads.

Tests of Plants.—The following series of tests have been supplied by Messrs. Ernest Scott & Mountain on plants erected by them :—

1. **Test of Plant for the Birkenhead Electricity Works.**—Combined plant, consisting of one $\frac{11\frac{1}{4}'' \times 21''}{10''}$ central-valve compound vertical engine (condensing), and 36″ x 18″ four-pole generator. March 22, 1902.

Full Load.—Water consumption per hour, 3,725 lbs.

Average electrical output during water-test = $\left\{\begin{array}{l}\text{273 ampères}\\ \text{550·2 volts}\end{array}\right\} = \left\{\begin{array}{l}\text{201·3}\\ \text{E.H.P.}\end{array}\right.$

Water per E.H.P. = 18·55 lbs. per hour.
Water per I.H.P. = 16·20 lbs. per hour.

Indicator cards taken during water-test :—

	High Pressure.			Low Pressure.	
	Top.	Bottom.		Top.	Bottom.
Diagram area .	1·55	1·7	Diagram area .	1·2	1·4
„ length .	2·75″		„ length .	2·8	
„ scale .	$\frac{1}{120}$		„ scale .	$\frac{1}{40}$	
Average mean effective pressure, lbs. per sq. in. .	70·9		Average mean effective pressure, lbs. per sq. in. .	18·5	

I.H.P. in h.-p. cylinder, less I.H.P. on rod = 123 − 2·7 = 120·3
„ „ l.-p. „ „ „ „ „ = 111 − 0·7 = 110·3
Net collective I.H.P. = 230·6

E.H.P. when cards were taken = $\left\{\begin{array}{l}\text{272 ampères}\\ \text{550 volts}\end{array}\right\}$ 200.

Combined efficiency, 86·7 per cent.

Pressure at stop-valve, 156 lbs. per sq. in. Steam-pipe pressure (engine side of governor valve) = 122 lbs. per sq. in. Vacuum, 23·5″.

Piston rods, $2\frac{3}{8}$″ diameter.

Speed of engine, 346 revolutions per minute.

Three-quarter Load.—Water consumption per hour, 2,992 lbs.

Average E.H.P. during water-test = $\left\{\begin{array}{l}\text{203·9 ampères}\\ \text{254·0 volts}\end{array}\right\}$ 151·5 E.H.P.

Water per E.H.P. = 19·8 lbs. per hour.
Water per I.H.P. = 17·1 lbs. per hour.

Indicator cards taken during water-test :—

	High Pressure.			Low Pressure.	
	Top.	Bottom.		Top.	Bottom.
Diagram area .	1·15	1·23	Diagram area .	1·0	0·99
„ length .	2·75″		„ length .	2·8″	
„ scale .	$\frac{1}{120}$		„ scale .	$\frac{1}{40}$	
M.E.P. . .	50·5	53·63	M.E.P. . .	14·3	14·14
Average M.E.P., lbs. per sq. in. .	52·06		Average M.E.P., lbs. per sq. in. .	14·22	

I.H.P. in h.-p. cylinder less I.H.P. on rod = 91 − 2·25 = 88·75 I.H.P.
„ l.-p. „ „ „ „ = 86·7 − 0·55 = 86·15 „
Net collective I.H.P. = 174·90

E.H.P. when cards were taken = $\left\{\begin{matrix}204 \text{ ampères}\\ 552 \text{ volts}\end{matrix}\right\}$ 150·94.

Combined efficiency, 86·3 per cent.

Pressure at stop-valve = 154 lbs. per sq. in. Steam-pipe pressure (engine side of governor valve) = 82 lbs. per sq. in. Vacuum = 23·3″.

Piston-rods, $2\frac{3}{8}''$ diameter.

Speed of engine = 347 revolutions per minute.

Twenty-five per Cent. Overload.—Water consumption per hour, 4,588 lbs.

Average E.H.P. during water-test = $\left\{\begin{matrix}342\cdot5 \text{ ampères}\\ 531\cdot5 \text{ volts}\end{matrix}\right\}$ 243·4 E.H.P.

Water per E.H.P. = 18·9 lbs. per hour.
Water per I.H.P. = 16·7 lbs. per hour.

Indicator cards taken during water-test :—

	High Pressure.			Low Pressure.	
	Top.	Bottom.		Top.	Bottom.
Diagram area	1·8	1·95	Diagram area	1·7	1·45
„ length	2·75″		„ length	2·8″	
„ scale	$\frac{1}{120}$		„ scale	$\frac{1}{40}$	
M.E.P.	78·3	85·0	M.E.P.	24·3	20·7
Average M.E.P., lbs. per sq. in.	81·6		Average M.E.P., lbs. per sq. in.	22·5	

I.H.P. in h.-p. cylinder, less I.H.P. on rod = 142 − 3·1 = 138·9
„ l.-p. „ „ „ „ = 136 − 0·8 = 135·2
Net collective I.H.P. = 274·1

E.H.P. when cards were taken = $\left\{\begin{matrix}341 \text{ ampères}\\ 531 \text{ volts}\end{matrix}\right\}$ 242·5.

Combined efficiency, 88·65 per cent.

Pressure at stop valve, 157 lbs. per sq. in. Steam-pipe pressure (engine side of governor valve) = 139 lbs. per sq. in. Vacuum = 22·9″.

Piston rods, $2\frac{3}{8}''$ diameter.

Speed of engine, 346 revolutions per minute.

2. **Test of Plant for Nettlefolds (Limited).**—Combined plant, consisting of a $\frac{12\frac{1}{2}'' \times 23''}{12''}$ C.V. engine, and 39″ × 13″ six-pole dynamo.

January 10, 1902.

Full Load.—Water consumption per hour, 6,811·2 lbs.

Average electrical output during water-test = $\left\{\begin{array}{l}870\text{ ampères}\\ 230\text{ volts}\end{array}\right\}$ 268·23 E.H.P.

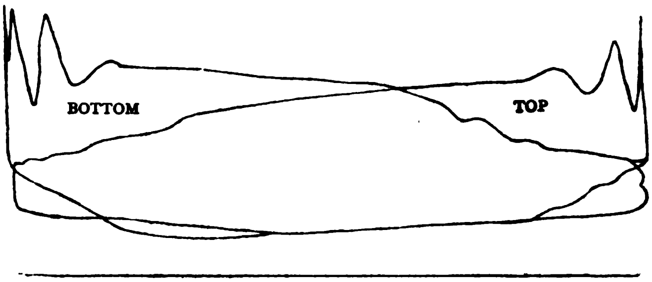
Water consumption per E.H.P. = 25·3 lbs. per hour.
Water consumption per I.H.P. = 22·3 lbs. per hour.

Indicator cards :—

High-pressure Cylinder.

Scale, $\frac{1}{120}$. Mean area, 1·97 square inch.
Length, 3·3 inches.
Average M.E.P., 71·6 lbs. per square inch.

FIG. 51.

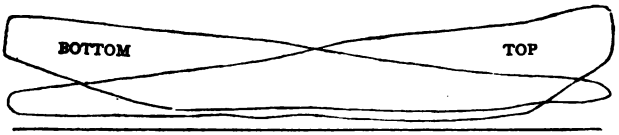


HIGH-PRESSURE CYLINDER. SCALE $\frac{1}{120}$.

Low-pressure Cylinder.

Scale, $\frac{1}{60}$. Mean area, ·93 square inch.
Length, 3·2 inches.
Average M.E.P., 17·6 lbs. per square inch.

FIG. 52.



LOW-PRESSURE CYLINDER. SCALE $\frac{1}{60}$.

Piston rods, 3 inches diameter.
Mean net area of h.-p. cylinder = 119·16 square inches.
„ „ „ l.-p. „ = 411·95 „ „
Revolutions, 320 per minute.

High-pressure cylinder, 12½ inches diameter. Low-pressure cylinder, 23 inches diameter. Stroke, 12 inches.

$$\text{High-pressure I.H.P.} = \frac{71·6 \times 640 \times 119·16}{33{,}000} = 165·39$$

$$\text{Low-pressure I.H.P.} = \frac{17·6 \times 411·95 \times 640}{33{,}000} = 140·44$$

$$\text{Collective I.H.P.} = 305·83.$$

$$\text{Electrical output when cards were taken} = \left\{\begin{array}{l}870\text{ ampères}\\230\text{ volts}\end{array}\right\} \begin{array}{l}268·23\\\text{E.H.P.}\end{array}$$

Combined efficiency, 87·7 per cent.

3. **Test of Plant for the South Durham Coal Company.**—The plant consists of—

One horizontal long-stroke compound engine capable of developing 440 I.H.P., of the following dimensions:—

Diameter of high-pressure cylinder	18 inches
Diameter of low-pressure cylinder	30 „
Length of stroke	40 „
Revolutions per minute	80
Steam pressure per square inch	100 lbs.

The engine is fitted with automatic expansion gear to both cylinders, and fitted with rope fly-wheel 16 feet diameter, grooved for fourteen ropes 1½ inch diameter.

The dynamo is of Scott & Mountain's six-pole type constructed for the following output:—

Total output in watts	220,000
Current in ampères	400
Volts at terminals	550
Approximate revolutions per minute	400

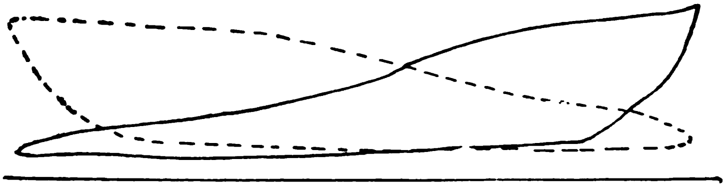
Test made February 28, 1902.

Constant quantities: Boiler pressure, 90 lbs. per square inch; stop valve, 86 lbs. per square inch; revolutions, 90 per minute; piston rods, 3¼ inches diameter.

Indicator cards: Six sets of cards were taken at intervals of ten minutes. The first set taken were as follows:—

	High-pressure Engine.	
	Back end.	Front end.
Area in square inches	1·2	1·4
Length in inches	3·5	
M.E.P. per square inch	34·25	40·0
Average M.E.P.	37·12	

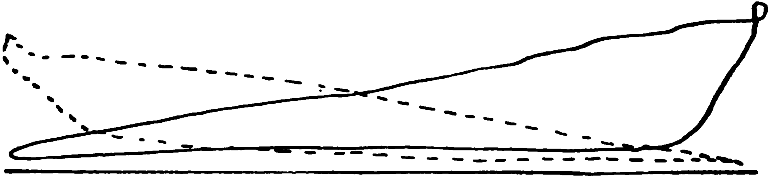
FIG. 53.



INDICATOR DIAGRAM FROM HIGH-PRESSURE ENGINE. SCALE $\frac{1}{100}$.
Front end cards, full lines; back end, dotted lines.

	Low-pressure Engine.	
	Back end.	Front end.
Area in square inches	0·9	1·2
Length in inches	3·875	
M.E.P. per square inch	3·72	4·96
Average M.E.P.	4·34	

FIG. 54.



INDICATOR DIAGRAM FROM LOW-PRESSURE ENGINE. SCALE $\frac{1}{16}$.
Front end cards, full lines; back end, dotted lines.

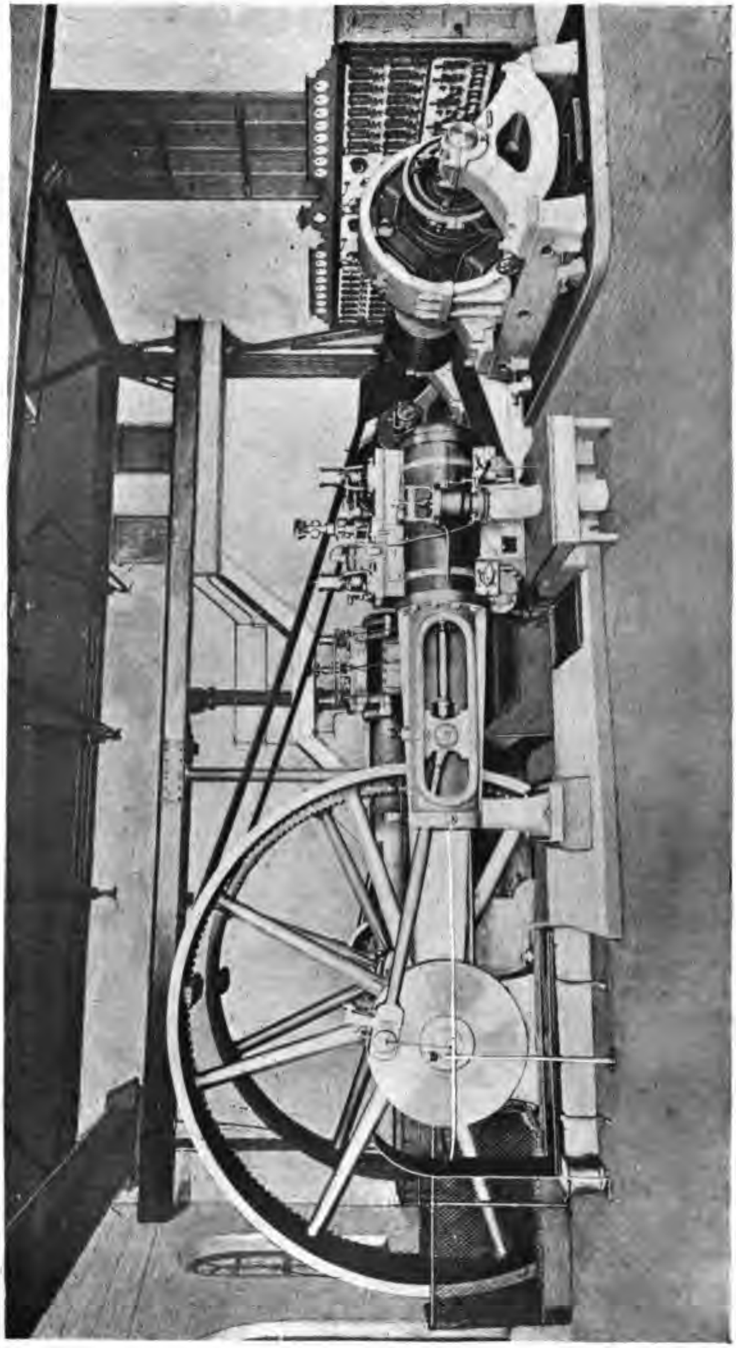
High-pressure I.H.P., less I.H.P. on rod = 172 — 2·98 = 169·02
Low-pressure I.H.P., less I.H.P. on rod = 62 — 0·37 = 61·63
Net collective I.H.P. = 230·65

The average of the six sets of cards was 227·53 I.H.P., out of which 23 I.H.P. was utilised for other purposes, which leaves a net I.H.P. available for driving the engine and dynamos of 204·53.

Average E.H.P. at dynamo terminals	140
Combined efficiency	68·5 per cent.
Lbs. of coal used per I.H.P. per hour	3·67
Lbs. of water used per I.H.P. per hour	29·8
Lbs. of coal used per E.H.P. per hour	5·3
Lbs. of water used per E.H.P. per hour	44·5

It will be seen that the engine and dynamo were working at less than half-load, which accounts for the comparatively high fuel and steam consumption. It is the intention at some future date to put down an additional pump and also to drive hauling machinery and coal cutters.

Fig. 55.



Rope-driven Electrical Generators.

Rope-driven Plant with High Efficiency.—The best results which Messrs. Ernest Scott & Mountain have obtained so far from a rope-driven plant are as follows :—

Single-cylinder engine with trip expansion gear, cylinder $19\frac{1}{2}$ inches by 40 inches, running at eighty-one revolutions per minute, fly-wheel 16 feet diameter, driving by twelve ropes $1\frac{1}{2}$ inch diameter.

Average area of cards (each end of cylinder) = 2·25 square inches.

Length of card, $3\frac{3}{4}$; scale of indicator spring, $\frac{1}{56}$.

$$\text{Mean pressure} = \frac{2{\cdot}25 \times 56}{3{\cdot}75} = 33{\cdot}6 \text{ lbs.}$$

$$\text{I.H.P.} = \frac{33{\cdot}6 \times 298{\cdot}64 \times 40 \times 81 \times 2}{12 \times 33{,}000} = 164{\cdot}2.$$

Voltage during test, 500 ; ampères during test, 210.

$$\text{E.H.P.} = \frac{500 \times 210}{746} = 140{\cdot}7 \text{ E.H.P.}$$

$$\text{Combined efficiency} = \frac{140{\cdot}7 \times 100}{164{\cdot}2} = 85{\cdot}6 \text{ per cent.}$$

Fig. 55 shows the plant referred to.

Arrangement of Engine-house, Engines, Dynamos, &c.—In a large installation, where everything is done by electricity, except perhaps the winding, it is advisable to split up the total power to be generated into units, so as to lessen the risk of a breakdown and consequent stoppage of the colliery. Especially is it important where ventilating machinery is driven by a motor, the stoppage of which might occasion serious accident. This practice, of course, reduces the efficiency of the installation, but present economy must always be sacrificed to safety.

The steam-pipe connections of these various units to the boilers must also be carefully designed, and divided as far as possible into sections, so that the bursting of one pipe would not necessarily stop all the engines ; a good practice would be to duplicate the steam-pipe connections.

Spare Plant in Case of Emergency.—The provision of an extra unit would relieve the engineer from a great deal of anxiety. With regard to the ventilating fan, the motor to drive this should certainly be kept in duplicate, just as is the case when driving by a steam-engine. Spare armatures should be kept for all continuous-current dynamos and motors.

Facility for Examination and Repair of Plant.—It is of great importance that the plant should not be cramped up, and in the case of a large installation an electric travelling overhead crane is of great use in handling the armatures, pistons, &c.

The dynamos and motors, when rope or belt driven, are very often placed on sliding rails, which enables the stretch of the belt or ropes to be taken up if required when running.

CHAPTER IV

THE STEAM-TURBINE

Parsons Turbine—De Laval Turbine.

In the ordinary steam-engine the power of the steam is made to give a reciprocating movement to the piston, which is converted into rotary motion by means of the connecting-rod and crank. Thus, at the end of each stroke the direction of motion is reversed, and consequently high speeds can only be maintained in engines of especially good construction and especially good lubrication.

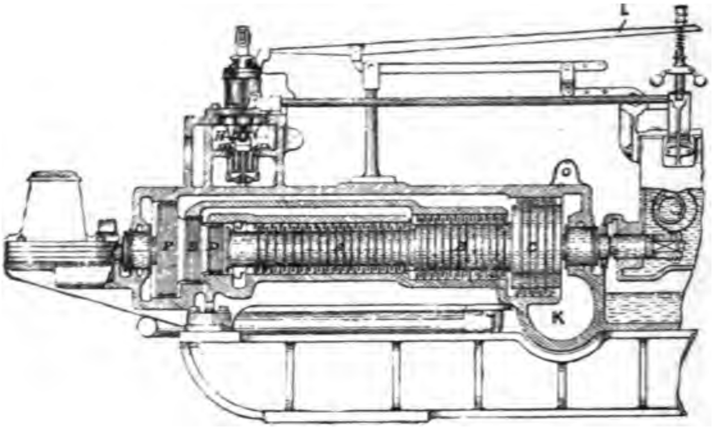
The steam-turbine is a rotary engine. There is no reciprocating motion, and the speed that can be attained is practically unlimited. There are two principal varieties of steam-turbine in use in this country—namely, Parsons' and De Laval's, the former being first placed on the market in the year 1884, and the latter on the English market in the year 1900.

Parsons Steam-turbine.

On referring to fig. 56 it will be seen that on the turbine shaft are three barrels of increasing diameter, A, B, C, with rings of projecting blades on their circumference. These barrels are enclosed in a cylindrical casting, on the inside of which is another series of blades. The rings of blades on the case nearly touch the barrels on the shaft, and the rings of blades on the shaft lie between those on the case and nearly touch the case. Fig. 57 is a view of a turbine with the cover removed, showing the rings of blades on the barrel.

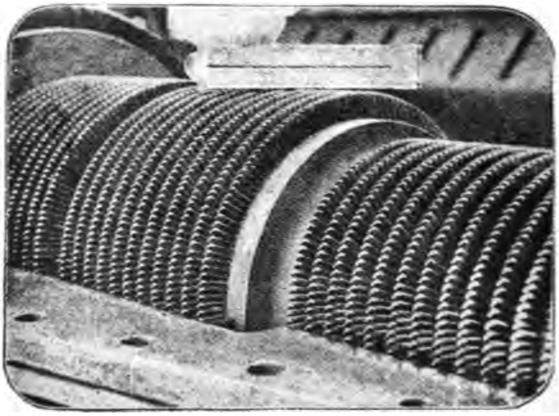
It will be noticed that there are three dummy barrels, D, E, and F (fig. 56), also fixed on the turbine shaft. These correspond in size to the barrels, A, B, and C, and communicate with them by passages in the casting. By this means the pressure is equalised in both directions and end thrust is prevented. The steam is admitted through a double-beat valve, H, and, entering the cylinder at J, passes first through a ring of fixed blades and is projected in a rotational direction upon the succeeding ring of blades on the barrel, imparting to them a rotational force. The diameters of the barrels are increased to suit the increasing volume of the steam as it expands, so as to keep the velocity at which the steam travels through the turbine practically constant. The exhaust port, K, is connected direct to the condenser, which may take the form of a surface condenser or a jet condenser, according to the nature of the water. The steam is not admitted continuously to the turbine, but in a series of gusts, the lever, L, being periodically moved up and down by means of an eccentric worked from the turbine shaft.

FIG. 56.



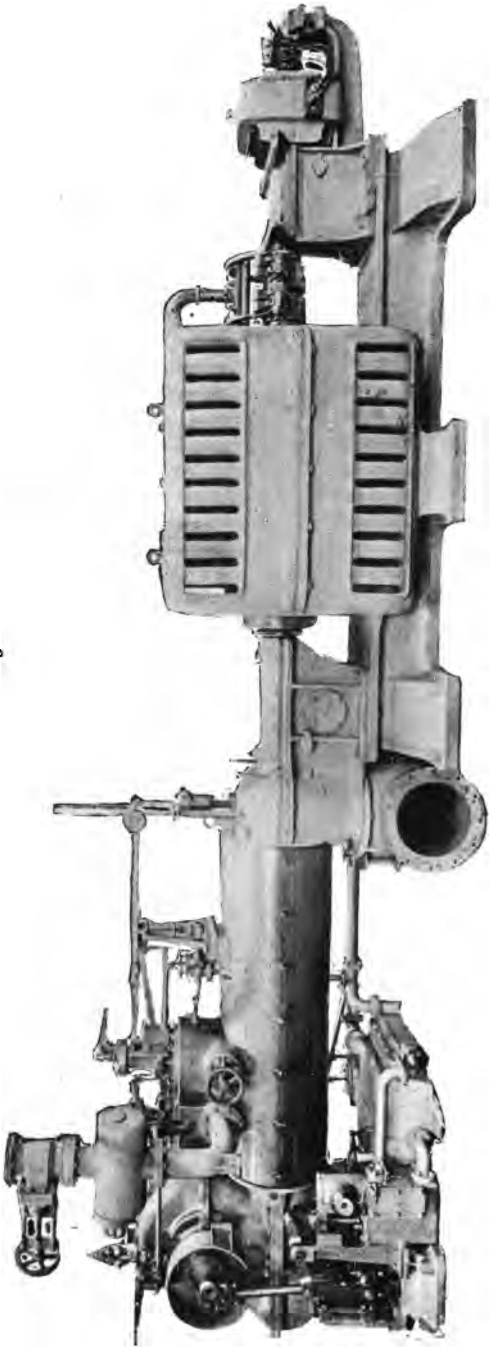
PARSONS STEAM-TURBINE.

FIG. 57.



PARSONS TURBINE, WITH COVER REMOVED.

Fig. 58.



300-K.W. Parsons Turbo-alternator.

The duration of the steam admission is controlled by means of a governor, which regulates the height of the end of the lever. The number of gusts varies from 1 in 15 revolutions of the turbine shaft to 1 in 30. The speed of the turbine may be from 2,000 to 6,000 revolutions a minute, a common speed being 3,000 revolutions. When used for dynamo driving the armature is coupled direct to the motor shaft by means of a flexible coupling. Fig. 58 is from a photograph of a 300-k.w. turbo-alternator. Similar machines are being supplied to Denaby Main Colliery.

Steam Consumption of the Parsons Turbine.—When first brought out the turbine was popularly supposed to be very wasteful in steam, but long experience and improvements in the design have made it a very formidable competitor with the high-class modern condensing engine. The larger sizes are naturally more economical than the smaller ones, and although for colliery work such a large size as a 1,000-kilowatt steam turbine will probably seldom be met with, the following test is interesting. The machines tested were two 1,000-kilowatt steam-turbines for the new electric station of the city of Elberfeld, and a series of tests were made under the normal load, an overload of about 20 per cent., three-quarter load, half-load, and a quarter-load. The steam consumption per kilowatt per hour when working at normal load was 20·15 lbs.; overload of about 20 per cent., 19·43 lbs.; three-quarter load, 22·31 lbs.; half-load, 25·2 lbs.; quarter load, 33·76 lbs. It will be borne in mind that a kilowatt is 1,000 watts $= \frac{1,000}{746} =$ 1·34 E.H.P. (see page 9.)

While a colliery installation might for a very large concern require between 1,500 and 2,000 h.p., it would be divided up into a number of smaller units, say 250 or 300 h.p.

The following tests[1] of two 200-kilowatt continuous-current turbine dynamos show the steam consumption in the smaller sizes :—

Pressure of Steam above Atmosphere at Stop-valve	Superheat at Stop-valve	Vacuum in the Turbine Cylinder Bar=30″	Revolutions per Minute	Load	Steam Used	
Lbs. per sq. in.	F.°	Inches of Mercury		Kilowatts	Lbs. per hour	Lbs. per Kilowatt Hour
129	58	27·6	3,045	226	4,975	22·0
122	60	28·4	3,010	232	5,079	21·9
119	0	26·9	3,000	204	4,943	24·2
130	0	28·0	3,010	0	950	—

It will be noticed in the above test that in two cases the steam was super-heated. This has the effect of lessening the steam consumption, for the same reasons that would apply in other engines, and also by lessening the friction in the steam passages.

---

[1] *Trials of Steam-turbines for Driving Dynamos*, by the Hon. Chas. Parsons and C. G. Stoney; International Engineering Congress, September 1901.

Size and Weight of Parsons Turbine Dynamos.—The following table gives approximately the dimensions and weight of various sizes of turbine dynamos :—

Size of Turbo in Kilowatts	Speed, Revs. per Minute	Length		Width		Height		Weight
		Ft.	in.	Ft.	in.	Ft.	in.	Cwt.
50	4,000	15	6	2	0	4	0	79
100	3,500	19	0	2	8	5	8	134
200	3,000	22	6	3	6	7	0	221
300	3,000	22	6	5	9	6	0	270
1,000	1,800	37	0	8	0	9	6	930

Installation of Turbine Dynamos at Ackton Hall Colliery.—Although these machines are largely employed for central station electrical plants, with some exceptions they have only recently been introduced to colliery work. One of the first installations in this country was at the Ackton Hall Colliery, Featherstone, where the plant has been running very successfully for the last eight or nine years. The original installation is described in the 'Proceedings of the Institution of Mining Engineers.'[1]

'It consists of two Parsons 200 E.H.P. steam-turbines and dynamos working at 500 volts pressure and running at 3,000 revolutions per minute. The steam enters the turbine from a pipe 3 inches in diameter, and is admitted in periodic blasts, one in every fifteen revolutions of the turbine. The plant when originally installed was not condensing, and the makers guaranteed a water consumption per E.H.P. per hour of not more than 39 lbs. The complete machine measures 17 feet long by 3 feet wide, and no foundations are needed, the machine simply resting on india-rubber mats.'

Since the above paper was written several more turbines have been put down, taking the place of ordinary steam-engines, and the installation now consists of the following :—

Three continuous-current dynamos, each of 200 E.H.P. capacity at 500 volts; one 200 E.H.P. turbo-alternator, three-phase at 350 volts, with a periodicity of 42 per second ; two continuous-current turbo-dynamos, each of 57 E.H.P. at 220 volts; and one 400 E.H.P. continuous-current turbo-dynamo at 500 volts.

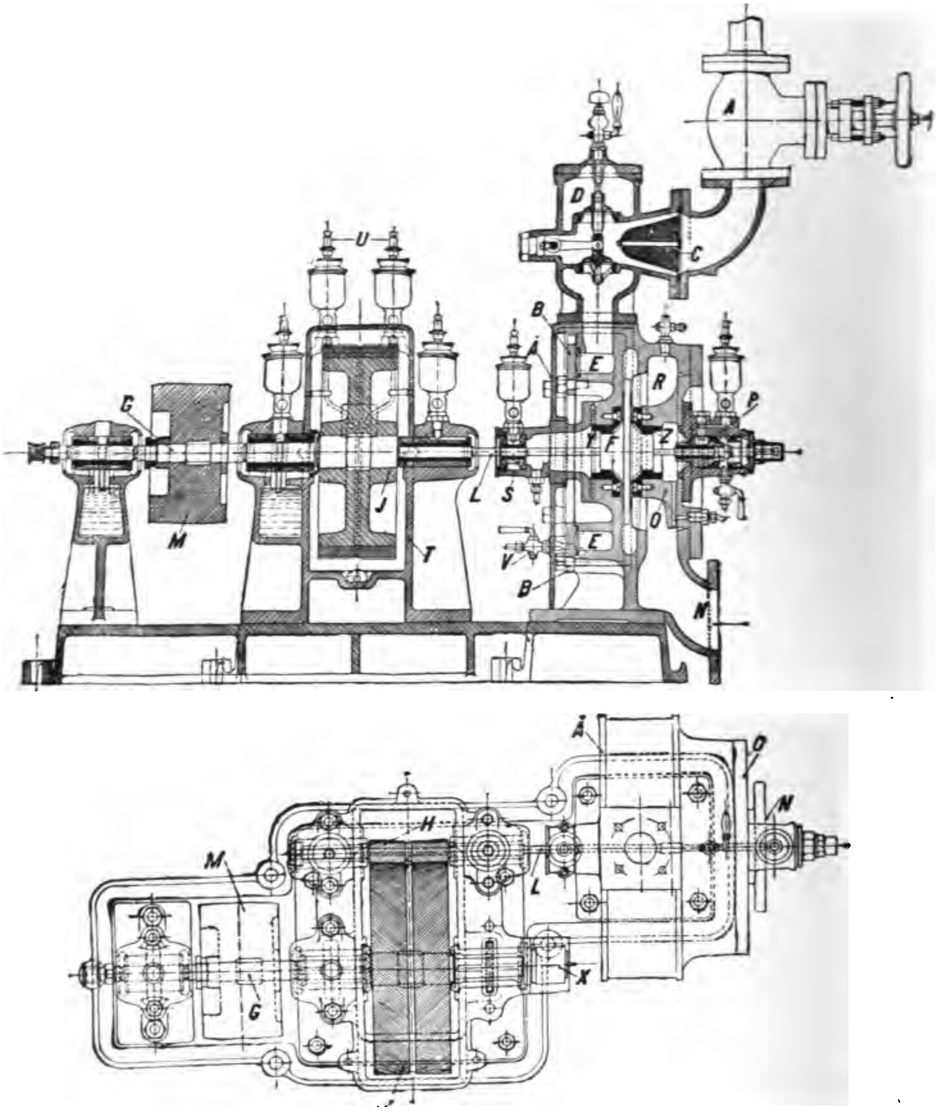
---

[1] 'The Use of Electricity at Ackton Hall Colliery,' by H. St. John Durnford and Roslyn Holiday; *Transactions Institute Mining Engineers*, xiii. 232.

The De Laval Steam-turbine.

This is somewhat different in principle from the Parsons, and is more closely allied to the ordinary water-turbine. Fig. 59 shows a sectional view

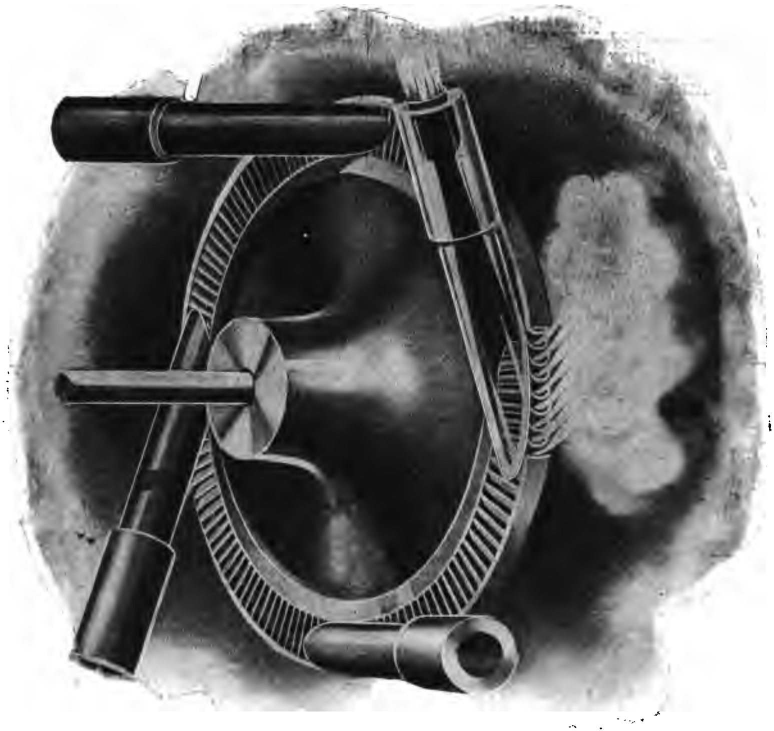
FIG. 59.



SECTION AND PLAN OF 20 H.P. DE LAVAL TURBINE MOTOR.

and plan of a 20 h.p. steam-turbine motor. The admission-steam enters the turbine after having passed the stop-valve, A, of the machine. This stop-valve is mounted direct on the inlet flange of the governor-valve case. Before the steam enters this valve it is passed through a strainer of wire gauze, C, which prevents any dust getting into the turbine case. In the governor-valve, D, which is regulated by the centrifugal governor of the turbine, the steam is throttled, so that only the amount which is required for driving the turbine at the load for the moment can enter the turbine case.

FIG. 60.



DE LAVAL STEAM-TURBINE, SHOWING BUCKET-WHEEL AND NOZZLES.

The high-pressure steam passes into the chamber, E, where it is distributed to a number of steam nozzles, which are placed at an angle of 20° to the vanes of the turbine wheel. The number of nozzles varies from one to twelve, according to the size of the machine. The passages in the nozzles are conical, the object being to make the steam expand as it passes through, and so give to it a very high velocity. The kinetic energy of this jet of steam is taken up in the buckets of the turbine wheel, against which the steam is blown, so imparting a rotary motion to the wheel. After doing its work the steam passes into the chamber, O (fig. 59), and through the exhaust opening, N.

The nozzles previously referred to are all provided with valves, so that some can be shut when the turbine is running below its normal load.

Fig. 60 shows the turbine wheel with its vanes or buckets.

The following table shows the speeds of the turbine wheels in various sizes of turbine:[1]—

Size of Turbine	Middle Diameter of Wheel		Revolutions per Minute	Peripheral Speed
				Feet per Second
5 h.p.	100 mm.	4 in.	30,000	515
15 ,,	150 ,,	6 ,,	24,000	617
30 ,,	225 ,,	8⅛ ,,	20,000	774
50 ,,	300 ,,	11¾ ,,	16,400	846
100 ,,	500 ,,	19¾ ,,	13,000	1,115
300 ,,	760 ,,	30 ,,	10.600	1,378

It will be seen that the turbine shaft revolves at a very high speed, but owing to the small diameter of the revolving turbine wheel there is no practical difficulty in designing wheels of sufficient strength; moreover, the turbine wheel is entirely enclosed, which renders the machine quite safe.

The speed of the turbine wheel is reduced in the machine by means of double helical gearing. In the smaller sizes up to 30 h.p., the pinion on the turbine shaft works with one gearing wheel, in the larger sizes there are two gearing wheels. Fig. 61 shows a 100 h.p. turbine dynamo; it will be seen that there are two armatures, each coupled to a large gear-wheel, while the turbine is coupled to a pinion which works between them. The speed of the dynamo shafts in a 150 h.p. turbine is 1,050 revolutions per minute. The armatures of the dynamo are directly connected to these main shafts. The speed of the machine is regulated by a centrifugal governor.

The turbine is condensing; any form of condenser may be used.

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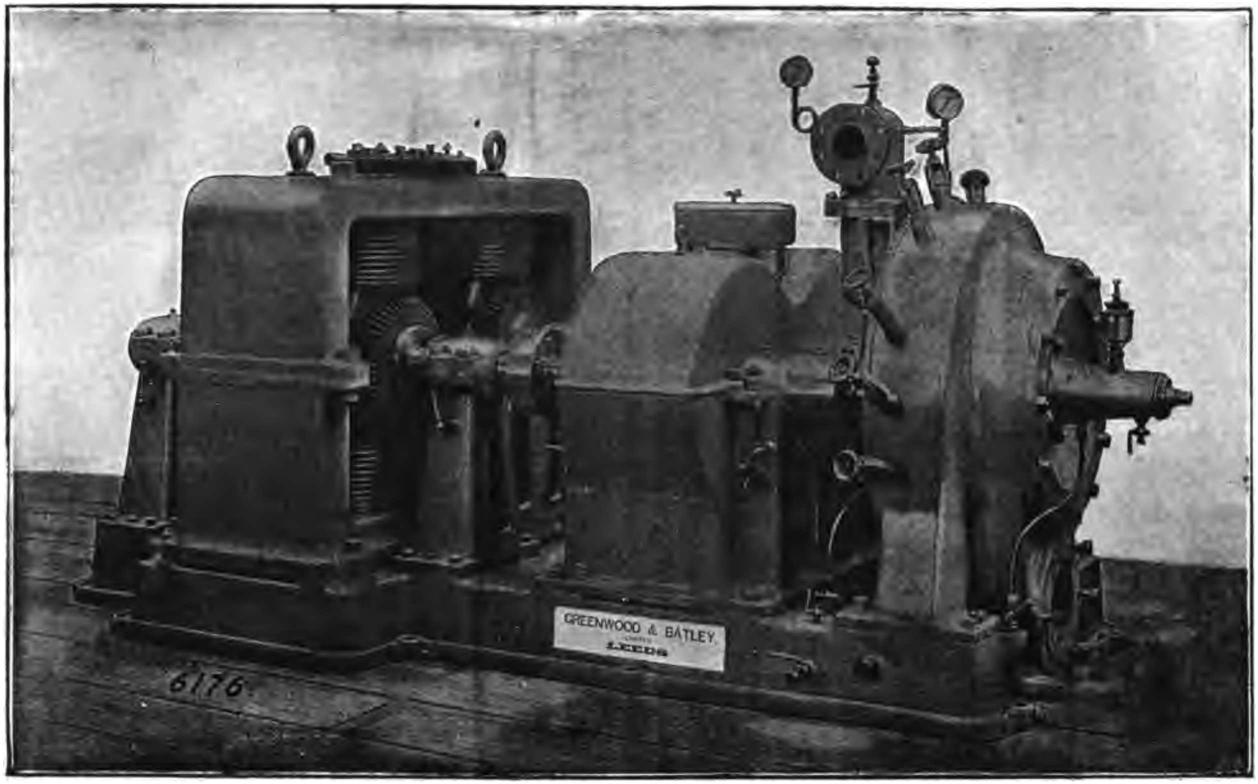
[1] Paper read before the Leeds Association of Engineers by Mr. Konrad Andersson, January 25, 1900.

FIG. 61.



100 H.P. DE LAVAL TURBINE DYNAMO.

STEAM CONSUMPTION OF THE DE LAVAL STEAM-TURBINE.

Size of Machine	Pressure of Admission Steam	Vacuum	No. of Nozzles open	E.H.P.	Lbs. of Steam per E.H.P. per Hour	Remarks
	Lbs. per sq. in.	Inches of Mercury				
50 h.p. turbine dynamo, test made in April 1895	113·8	26·3	6	50·05	24·3	Work for condensing is included
	113·8	26·3	5	40·79	24·8	
	93·9	26·9	4	25·34	27·5	
	74·0	27·5	3	12·87	32·0	
				B.H.P.	Lbs. of Steam per B.H.P. per Hour	
300 h.p. turbine motor, test made in December 1899	192·7	27·3	7	307·8	13·9	Work for condensing is not included
	196·3	27·6	6	259·0	14·5	
	196·3	27·6	4	175·0	14·3	
	190·6	27·8	3	123·3	14·7	
	196·3	28·1	2	75·2	17·0	
	213·3	28·5	1	31·9	21·3	

The following table gives approximately the dimensions and weights of various sizes of De Laval turbine dynamos:—

No. of Watts	B.H.P.	Revolutions per Minute	Weight		Space occupied					
					Length		Width		Height	
			Cwt.	lbs.	Ft.	in.	Ft.	in.	Ft.	in.
13,200	20	2,000	19	0	6	0	2	1	3	2
33,000	50	1,500	63	0	7	3	4	0½	4	1
66,000	100	1,050	142	75	10	3	5	6	5	2
100,000	150	1,050	157	53	11	1	5	1	4	8

Advantages of the Steam-turbine.—The chief use of the steam-turbine in this country has been found in direct driving of dynamos. It has so far not been found practicable to take power off the motor shaft by means of a belt or ropes, as this would introduce a side pull on the turbine shaft and cause great trouble with the bearings.[1]

Among the advantages of using the turbine for the generation of electricity are the following:—

1. A great saving in floor space, and consequent cheapening of engine-house.
2. Heavy foundations are not found necessary, owing to the freedom of the machine from vibration. It has been found possible, indeed, to entirely dispense with foundation bolts.

---

[1] Power may be taken, however, from the second motion shaft, either by belt or ropes.

3. There is no rubbing action in the cylinder, consequently no oil is employed except in the bearings, and this should reduce the amount of oil in the exhaust steam.

4. The steam consumption under colliery conditions, where the same degree of perfection cannot be attained as in electrical generating stations, will usually be somewhat higher than a first-class compound condensing engine, but the saving arising from Nos. 1 to 3, and the absence of the difficulties attending reciprocating engines summed up in the word knocking, will undoubtedly more than balance any extra cost on this account.

CHAPTER V

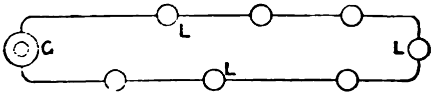
DISTRIBUTION OF ELECTRICAL ENERGY

Various Systems : Series ; Parallel ; Two-phase ; Three-phase.

THIS is a subject of great importance, and one that requires careful forethought in planning any new system of supplying electricity to either lamps or electro-motors. There are a number of systems of distribution, each possessing advantages which another one does not, and these will now be considered.

Series System.—This is represented diagrammatically in fig. 62, where all the lamps, L L, are in simple series with one another and with the generator, G. This is a constant-current system, the E.M.F. of G being made to vary proportionally to the number of lamps, L, alight. The system is almost entirely restricted to arc-lamp lighting, though there is another system with which such lamps are used. The current is, of course, the same at all parts of the circuit, being equal to that taken by any lamp which varies from 10 to 12 or 15 ampères. Hence, though the insulation must be good on account of the high voltages (up to 3,500) often used, the section of copper, and therefore the amount of copper sunk, in this system is small. The system is only used for direct current at high pressure.

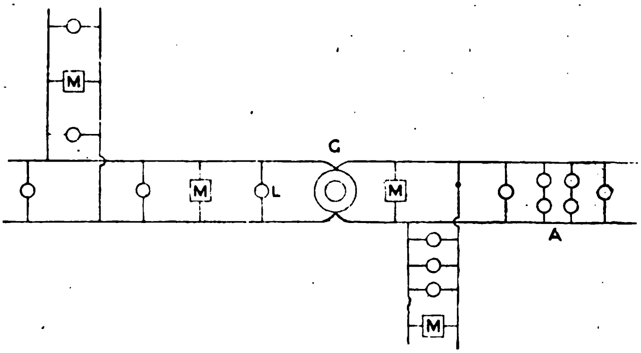
FIG. 62.



SERIES SYSTEM.

Two-wire Parallel System.—This is shown in fig. 63, and consists of two mains, running all the way from the generator, G, to where the power is required. The lamps, L, and motors, M, are connected across the mains where required, and are said to be in parallel with one another across those mains. In this system the voltage between the mains is approximately constant everywhere; but the current developed is equal to the sum of all the currents taken by the separate lamps and motors, and therefore in a large system this amounts to a great quantity, and will require a large amount of copper to be sunk in the mains, unless the pressure across them is considerable. This at the present day would be either about 100 or 200 volts where there is much lighting to be done, but in the case of a circuit where motors formed the chief load the voltage would be higher. If the voltage is 200, we could employ 200-volt motors and either 200-volt

FIG. 63.

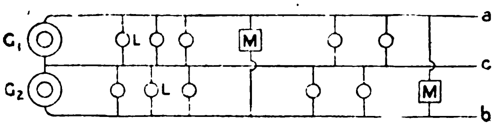


TWO-WIRE PARALLEL SYSTEM.

glow-lamps or connect two 100-volt glow-lamps in series across the mains, as shown at A, when, if one of the two fails, the other will go out also. These could also represent arc lamps of the 100-volt enclosed type, two being in series across the 200-volt mains; or, lastly, 200-volt enclosed arc lamps could be used, but this is not to be recommended. This system is widely used for both direct and single-phase alternating currents.

Three-wire Parallel System.—This is shown in fig. 64, in which

FIG. 64.

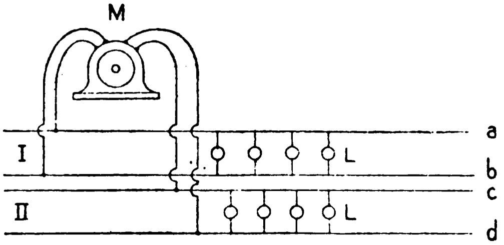


THREE-WIRE PARALLEL SYSTEM.

there are two similar generators, G_1 G_2, connected in series, and three distributing mains running from them as shown. The middle wire and one *outer* main form one *section*, and the middle wire and other *outer* main the other *section*. Lamps are connected across the two sections in such a way that, as nearly as possible, the same number shall be alight at the same moment. If equality were always exact, the middle wire (*c*) might be very small and not even connected to the junction of G_1 G_2. It is, however, usual to make *c* one-half the section of *a* or *b*, as there is generally a want of balance of at least 10 per cent. in a well and carefully planned system, though often far more. In the remote contingency of *all* the lamps, &c., being out on section *a c*, say, then *c* would have to carry the current for section *c b*—in fact, the same as *b*. A motor, M, would be placed across the outers, *a b*, so as to avoid throwing out the balance when switched on and off and affecting the voltage on the lamps. The advantage of the three-wire over the two-wire system lies in the increased voltage, for, suppose G_1 G_2 each gives 200 volts, that between *a* and *b* equals 400 volts, and we may regard the two sections as being in series. Hence, twice the power can be transmitted for the *same current* in the three-wire than was possible in the two-wire system with only a small percentage increase of copper laid out, due to the extra main. This system is applicable to both direct and single-phase alternating currents, for both of which it is widely used. In the latter, however, a single static transformer takes the place of G_1 G_2; the primary being connected by two mains to the alternator, the secondary being in two halves, each of which feeds one of the two sections. The total power delivered equals the sum of the two powers given to the two sections.

Two-phase Four-wire System.—This is shown in fig. 65, the pair of mains, *a* and *b*, going to Phase I. and the other pair to Phase II. All four mains are the same size, and the voltages across I. and across II. are equal. Lamps, L, are connected as shown, and, of course, a two-phase motor, M, would be connected to all four mains. The total power transmitted equals the sum of that in the two sections or Phases I. and II.

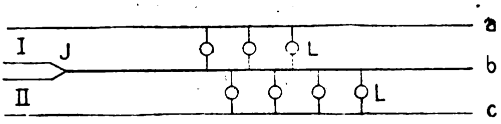
FIG. 65.



TWO-PHASE FOUR-WIRE SYSTEM.

Two-phase Three-wire System.—This is shown in fig. 66; two mains, one from each phase, are connected together, as at J, to form a single third main, *b*, which is $\sqrt{2}$ times the sectional area of either *a* or *c*, because it has to carry $\sqrt{2}$ times greater current. The voltage between *a* and *c* will be $\sqrt{2}$ times that between *a* and *b* and between *b* and *c*. This arrangement is generally used for transmission only, usually at high pressure, as the amount of copper required is only 85 per cent. of that needed in fig. 65 for the same power transmitted and the same maximum voltage between wires.

FIG. 66.



TWO-PHASE THREE-WIRE SYSTEM.

Three-phase System.—This requires three mains of equal section, and if the load is one of lamps only, the power delivered in such a system is equal to $\sqrt{3}$ × ampères in one main × voltage between two mains; providing, of course, the three sections are equally loaded. In this system only 75 per cent. of copper is required in the main, as compared with the two-wire single-phase or four-wire two-phase system for equal power transmitted and equal drop of voltage and pressure at the lamps.

The two-phase system is easier to regulate than the three-phase when lamps and motors are combined, but for motors only the three-phase system is the best and simplest to regulate. In this latter system the three wires can be run side by side as one cable, or can be separated to any distance required to suit convenience. In the workings of a mine three separated mains might be better, for if a fall occurred and one was broken, the other two mains might escape. If all three were bound together in one cable, all might be damaged by a fall of the roofing. In cases where current for lighting and power purposes is taken from the same circuit, switching a motor into or out of circuit may affect the voltage, and therefore the brilliancy, of the lamps burning on the circuit. This is certain to occur except when the mains are of ample cross-section or only small motors are being switched on or off, or except when the distributing mains are 'fed,' as it is termed, at frequent intervals by separate mains, called feeders, which run from the same or a similar dynamo in the generating station *direct* to the *feeding points.*

CHAPTER VI

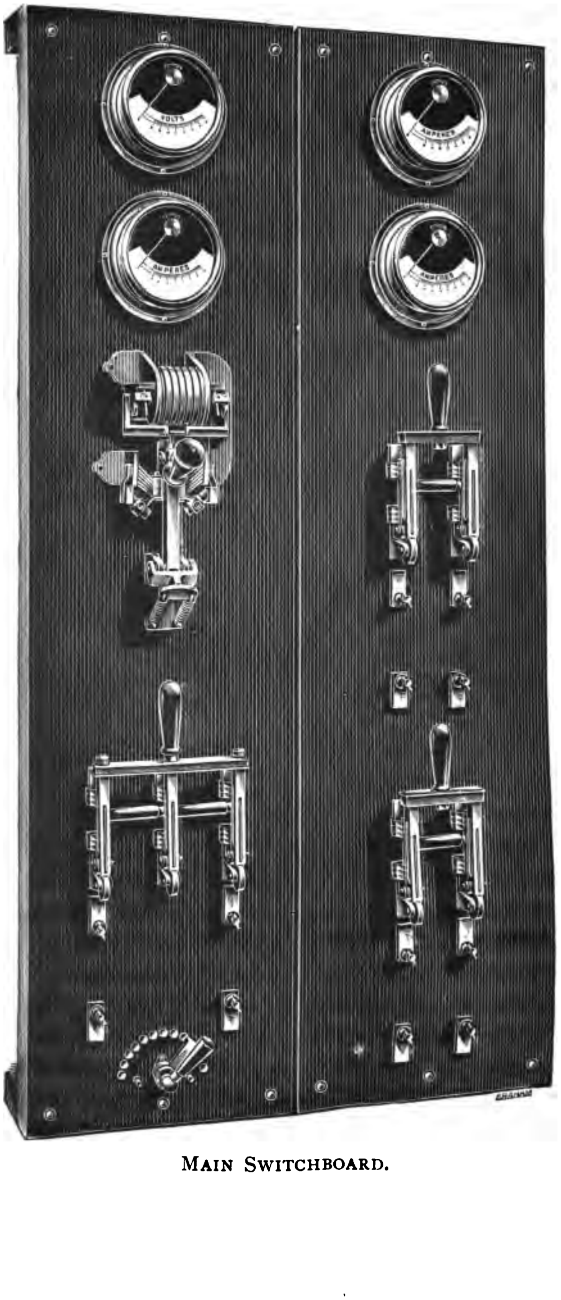
STARTING AND STOPPING ELECTRICAL GENERATORS AND MOTORS

Generators—Motors—Switchboard—Starting Resistance—Switches—Anti-Sparking Oil and Enclosed Switches—Lightning Arresters—Fuses—Magnetic Cut-outs—Ampère-meter, Voltmeter, Wattmeter, Electricity-meter.

Generators.—We will assume that the first start is in contemplation, and that the connections between generator and switchboard are correct.

The first thing should be to see that the oiling arrangements are in working order, and the brushes adjusted to a suitable pressure on the commutator or collecting rings. This should be as light as is compatible with a good rubbing contact. The *main current switches* (*vide* page 109) being *open*—*i.e.*, not making contact—start up the generator by the engine to the rated speed; then in the case of alternators switch on the exciting current and adjust its strength, by means of the rheostat in series with the field coils, so as to give the required voltage for the circuits. If now these last-named have shown a good insulation resistance, close the main-circuit switches, when the current will be available in the various circuits. Should the *exciter* or direct-current dynamo, usually driven by the alternator, not excite itself, as is often the case with new machines, the switch in the exciting circuit should be opened, and the field coils should be disconnected from the armature and connected to a source of direct current in such a way that they are temporarily magnetised, so as to develop the right polarity. The current being cut off after a minute or so, they are re-connected in their proper place, when usually there is no further difficulty in getting them to excite on closing the exciting-circuit switch. Almost any small direct current will serve to create some residual magnetism after it is cut off, and it is on this that the *building-up*, as it is termed, or self-exciting, of direct-current machines depends. The same remarks apply as to *starting up* direct-current generators, except that in starting up they usually excite themselves. If not, apply the preceding method of getting them to do so. In no case should a generator be switched into circuit until it is generating the required voltage for that circuit as indicated on the voltmeter on the switchboard, and in direct-current machines this can be obtained by either speed variation or by rheostats in the shunt circuit of the dynamo. In this connection it will be remembered that the greater the exciting current, and therefore the field, the greater will be the E.M.F. for a given speed.

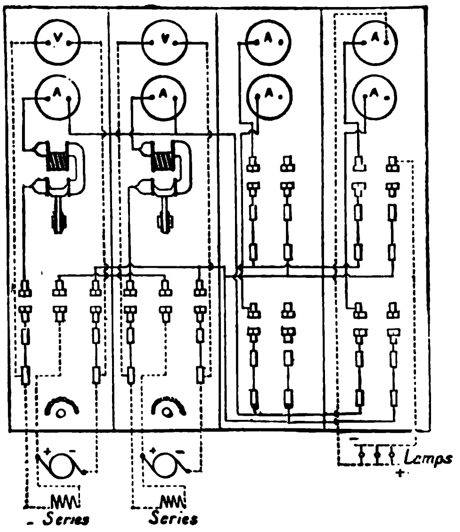
FIG. 67.



MAIN SWITCHBOARD.

Motors.—When installing electro-motors in a mine, especially a damp mine, it is often found beneficial to thoroughly dry the motor by baking it in an oven at some suitable temperature, say 60° or 70° C. above that of the air, before installing in the mine. This operation thoroughly dries the insulation of all the copper circuits, and seems to prevent the absorption of moisture in it afterwards. In the experience of the authors several motors not so treated have given trouble from their insulation breaking down, while those baked in the above manner have given no trouble in this respect at all.

FIG. 68.



— *Indicates cable connections to dynamo & circuits*

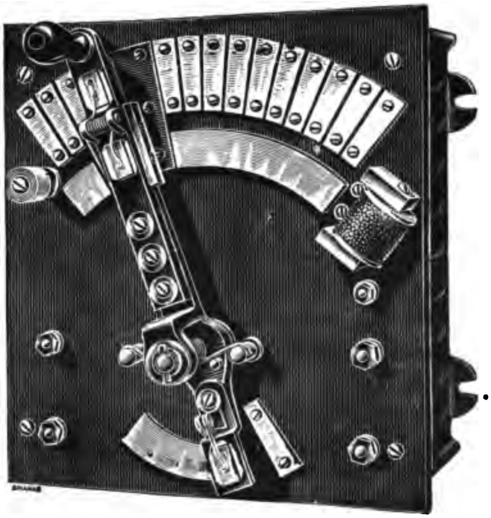
CONNECTIONS OF SWITCHBOARD.

In starting a direct-current motor, assuming that all connections are correct, the first point is to see that the oiling arrangements are in good working order, and that the starting resistance is *full in*; for suddenly switching the current on to the machine with no or very little resistance in series with its armature would not only cause a heavy rush of current, which would blow the protecting fuse, but might damage the armature conductors. The switch may next be *closed* and the starting resistance *gradually* cut out until the motor is left working on the mains by itself. As load is put on, the speed, if it falls, can be raised by weakening the field of the machine—*i.e.*, by increasing the resistance in series with the field-coils.

In stopping motors the resistance in the main rheostat should always be inserted to the full before breaking the main switch. There are, however, automatic switch rheostats which combine these two operations at one and the same time.

Switchboards.—These are enamelled slabs of slate, marble, or other insulating material, to which are fixed all the necessary appliances, such as measuring instruments, switches, cut-outs, and rheostats, for regulating and controlling the supply of the electric current. Figs. 67 and 68 show the general view and diagram of connections of a main switchboard made by the General Electric Company for the parallel running of two dynamos. At the top (fig. 67) are two ammeters and two voltmeters of the Stanley type (page 110). Underneath the left-hand instruments is a Stanley automatic minimum cut-out. Lower still is a three-pole Peel switch with double-pole fusible cut-out terminal underneath, and at the bottom a 13-point shunt-regulating switch. This is the dynamo panel. The circuit panel, on the right, contains the am- and volt-meter, two double-pole switches with fuse cut-outs. Combining another similar pair of panels with that of fig. 67, we obtain four, of which fig. 68 is the diagrammatic sketch. There are, of course, very much larger and more elaborately-equipped main switchboards, but this description will serve our purpose sufficiently well.

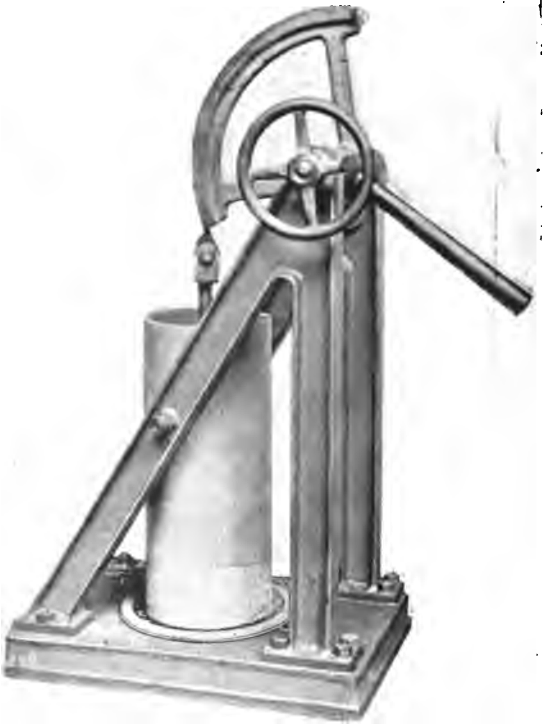
FIG. 69.



MOTOR-STARTING AUTOMATIC SWITCH RHEOSTAT.

Motor-starting Rheostats.—These are appliances for starting up a motor to full speed by the adjustment of the resistance in circuit without fear of injuring it, and at the same time for immediately switching it automatically out of circuit should the field of the motor cease to act or the supply of current be cut off. Fig. 69 shows one type made by the General Electric Company, London. It consists of a slate panel, on which are fixed the multiple-way contact blocks, which are connected to suitably-adjusted resistance coils of bare high-resistance wire. To start the motor when connected to this starting resistance, the contact lever is *slowly* pulled round clock-wise over the contact blocks, thus cutting out resistance in the main circuit until it is as far to the right as it will go. The electro-magnet then holds it there if the field is fully excited. The motor is now running at full speed light. If the supply is cut off the lever is released by the magnet (which fails) and flies back under the action of a strong spring, thus cutting out the motor.

Fig. 70.

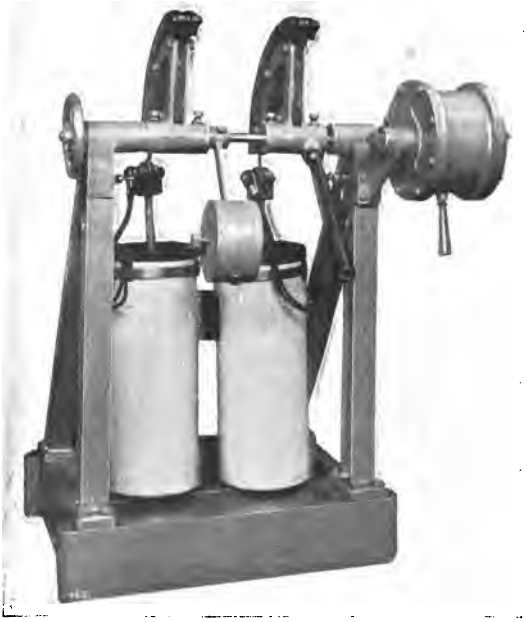


Single-pole Water Switch (Scott & Mountain).

Switches.—For mining work, at all events in the 'workings' where it is possible for gas to accumulate, either *liquid-break* or *enclosed switches* should be used, so as to avoid the possibility of firing the gas. Figs. 70

and 71 show respectively a single- and a double-pole liquid switch. Referring to the former, it consists of a grooved sector, provided with a handle, and pivoted on a horizontal spindle supported by the framework shown. A flexible cord hangs from the sector, and is capable of raising or lowering a contact immersed in oil, or other suitable liquid, contained in a vessel the lower part of which supports a fixed contact piece. The contact between the fixed and movable blocks or pieces is therefore made or broken in the liquid, and, therefore, the spark is immediately extinguished, and can never get to the surrounding gas. The form of liquid switch illustrated is made by Messrs. Ernest Scott & Mountain, of Newcastle-on-Tyne. Fig. 71 shows the double-pole form of similar construction, and fig. 72 another variety of liquid switch, both made by Messrs. Scott & Mountain. In this latter, by turning the hand-wheel at the top, the central plate is lowered on to the bottom of the outer case containing liquid, which completes the circuit; the moving part moves along insulating guides and cannot touch the case, and so forms one pole of the switch.

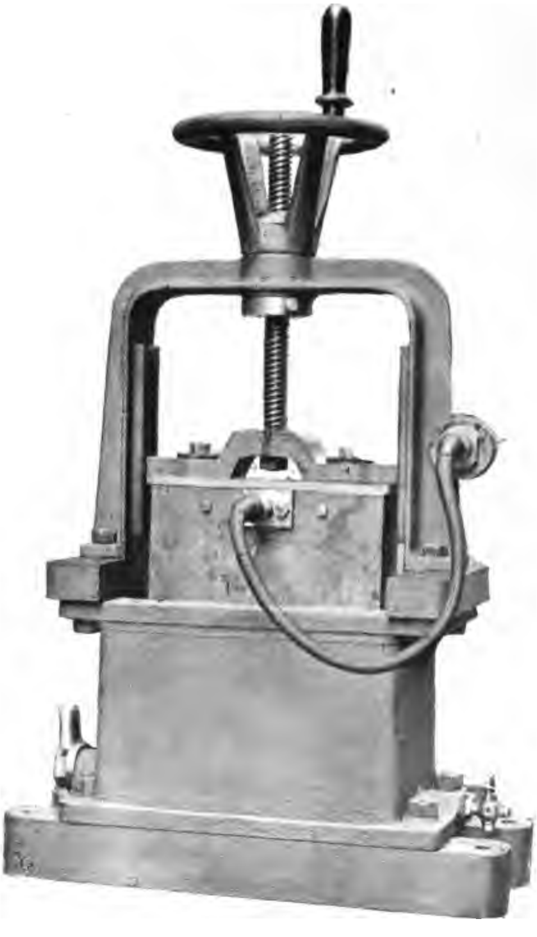
FIG. 71.



DOUBLE-POLE WATER SWITCH.

In the case of enclosed switches the containing-box must be as air-tight as possible, and be capable of withstanding the explosion of its contents of gas without communicating it to the gas outside; and for that reason the internal air space must be reduced to the smallest possible amount, and any openings through which air can pass must be so narrow and long that the flame of an internal explosion would be extinguished in passing; the smaller the total amount of openings in proportion to the cubic contents of possibly explosive gas, the longer must be the narrow passage to extinguish the gas flame. In testing safety-lamps it has been found that the holes in the wire gauze of a Clanny lamp are sufficient in number and total area to allow the passage of all the exploded gas that the lamp can contain at such

FIG. 72.

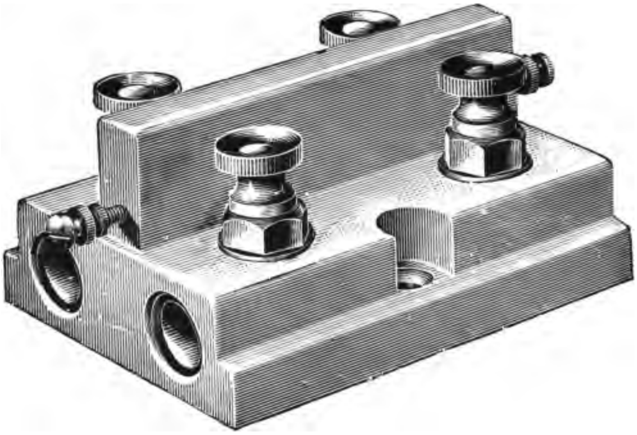


SINGLE-POLE WATER SWITCH.

a slow speed that it is cooled by the wires below burning point before it gets outside; but if the gauze is covered up for three-quarters of its area, the flame would be forced through the remaining part. The thickness of the wire gauze is about $\frac{1}{50}$ inch, and that is the length of the passage; the width of the passage is about $\frac{1}{70}$ inch. If the passage is made 1 inch long it would have fifty times the cooling effect; but if it is a slot instead of a pipe it would have only one-half the cooling effect; thus a slot 1 inch × $\frac{1}{70}$ inch in section × 1 inch long would probably be twenty-five times as effective for cooling as one hole in the gauze of a safety-lamp.

Lightning Arresters.—These are appliances which are inserted in the circuit of an overhead main to protect the main and machines, &c., connected with it, from fusion due to discharges of lightning.

FIG. 73.



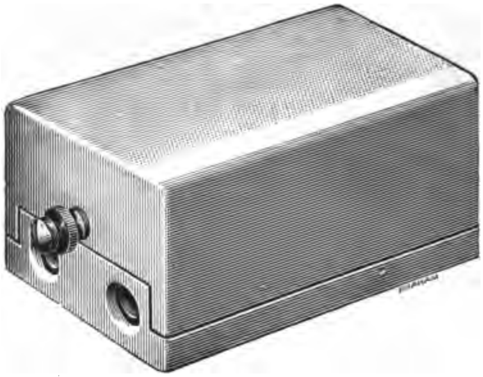
DOUBLE-POLE CUT-OUT (COVER OFF).

They are important adjuncts, as the line wires are liable to be struck at any moment when laid above ground, or if there is any electrical disturbance heavy discharges may take place along the wire, even without an actual flash. There are several well-known forms, and amongst them we may take the Thomson-Houston magnetic blow-out arrester. This consists of an electro-magnet terminating at its upper end in two upright metal horns, which curve away upwards from each other. The lightning on striking the line connected to one horn leaps across the short air gap between the lower ends of these horns, thereby causing the live current to flow to earth through the electro-magnet, one end of the coil of which is connected to the other horn. This, becoming magnetised, blows the arc across the horns higher up, until the gap is too long for the arc to exist, when it goes out.

This form of arrester can deal quickly with any number of successive discharges, which is an advantage. In addition to lightning arresters, lightning conductors should be fitted to the posts or other erections employed to support the electric overhead wire; these conductors being simply wires making good contact with the earth at the foot of the post, and projecting some 12 inches or more above the top of it.

Cut-outs.—These are devices for protecting the circuits and machinery from abnormal overload currents, which, if they did not actually fuse or burn up the machines or mains, would ruin the insulation of them, and might set fire to the premises in which they were placed. Fig. 73 shows one type of double-pole 'cut-out' known as the 'Champion,' and supplied by the General Electric Company, London. It consists, as seen, of a porcelain or china moulding, carrying four terminals, to the bases of which (not visible) are fixed metal cups, or thimbles, for soldering the main cables into. The two mains are cut, the ends of one being soldered to the two terminal cups on one side of the raised ridge, and the ends of the other to the pair on the other side. A piece of wire, made usually of nearly pure tin, which melts at a low temperature, is clamped under the nuts of each pair of terminals, and the china cover fixed, as seen in fig. 74. The gauge of fuse wire is so chosen that it melts on the current attaining a certain known strength, and cuts the current off. It is called 'double pole,' because a fuse is inserted in each main. There are many other forms of cut-outs, but space will not permit of their description.

FIG. 74.



DOUBLE-POLE CUT-OUT (COVER ON).

Magnetic Cut-outs.—These are cut-outs either by themselves or in combination with switches, which work solely by the electro-magnetic effect of the current, and not by the heating effect, as just instanced. The electro-magnetic cut-out switch is so arranged that when the current attains a certain strength a trigger is released by the electro-magnet, and causes the switch to spring open. Circuit can only be made again by closing the switch in the usual way. The cut-out portion can be adjusted for a range of 50 per cent. below to 50 per cent. above normal current. As soon as the current reaches the amount to which the instrument is set, the switch is opened and the current stopped. Figs. 75 and 76 show this kind of switch, closed and open respectively, as made by the General Electric Company, London.

Electrical Measuring Instruments.—The practical electrical engineering measuring instruments in use at the present day take a great many different forms, but all work on principles which depend on one or other of the properties of an electric current (*vide* page 3)—viz., the *electro-magnetic*, *electro-static*, *chemical*, and *thermal* properties. But, whatever the principle on which they work, they may be classified as follows :—

Fig. 75.

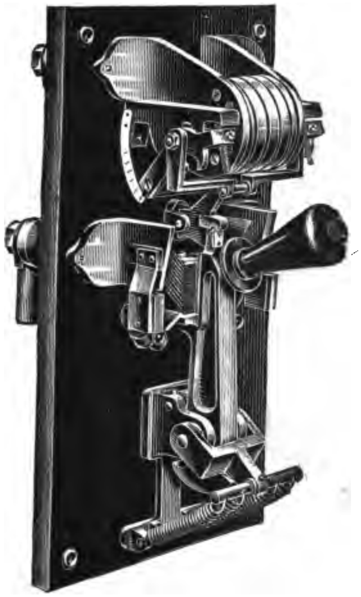
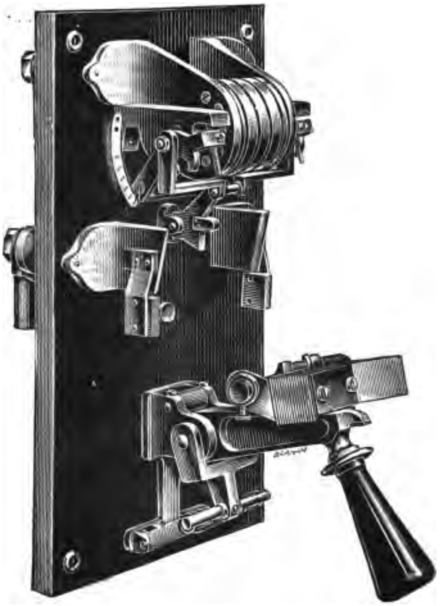


Fig. 76



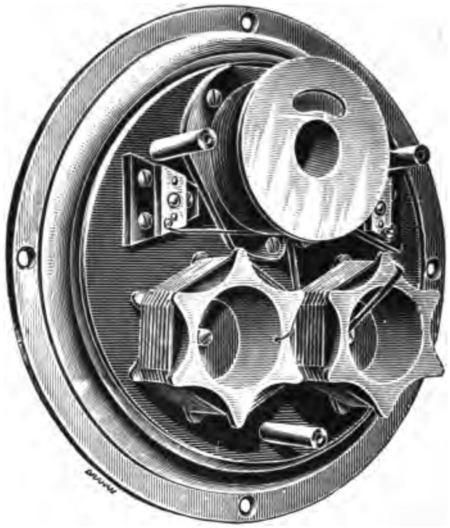
(Closed) Automatic Release Switch. (Open)

Ammeters for measuring the current in a circuit.
Voltmeters for measuring the voltage across a circuit.
Wattmeters for measuring the power given to a circuit.
Electricity-meters for measuring the energy given to a circuit.

We will now briefly consider each of these in turn. Ammeters and voltmeters of the electro-magnetic type differ merely in the winding of the actuating coil, so that we will confine ourselves to describing simply one well-known form of this type—the Stanley—made by the General Electric Company, London.

Fig. 77 shows the back view of a voltmeter, with case removed. The bobbin at the top is wound with a large number of turns of fine silk-covered copper wire, and is connected in series with a large resistance made of fine wire of a special alloy, which alters its resistance very little with slight change of temperature, and wound on the two porcelain bobbins or frames shown below it. The form of this is such as to allow the heat generated by the current in the wire to escape easily. The extremities of this combination are connected to the two terminals of the instrument. The ammeter of this make only contains the top bobbin, now wound with *thick* copper wire for carrying the main currents. In all cases the internal opening in the bobbin contains a piece of soft iron carried on a light spindle, suitably pivoted in jewelled centres, and carrying the pointer, not seen in fig. 77. When a current flows through the coil the interior becomes a powerful field, which alters the position of the iron needle, thereby causing the pointer to take a certain position on the scale corresponding to the known measured current or voltage. Figs. 78 and 79 respectively show a voltmeter and ammeter of this make complete.

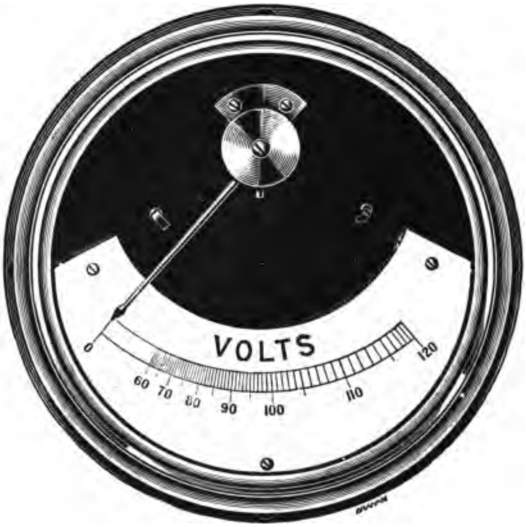
FIG. 77.



INTERIOR OF ELECTRO-MAGNETIC VOLTMETER.

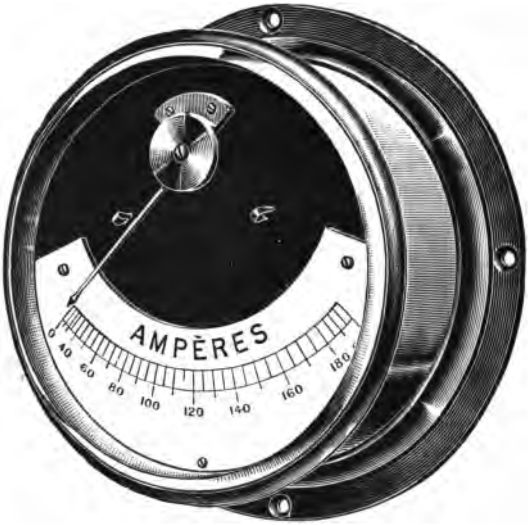
Another type of instrument widely used nowadays, though more expensive, is that known as the moving coil permanent magnet ammeter and voltmeter. In these the scale is graduated in equal divisions throughout, and the pointer immediately takes its position corresponding to any altered current or voltage without swinging to and fro a few times either side of it.

FIG. 78.



ELECTRO-MAGNETIC VOLTMETER.

FIG. 79.



ELECTRO-MAGNETIC AMMETER.

This is an advantage when a current or voltage has to be measured which fluctuates. Some of the different makes of the type of instrument described above are provided with damping devices to bring the pointer quickly to rest. Such instruments are called 'dead beat.'

A **Wattmeter** is a combination of an ammeter and voltmeter, which by the deflection of its pointer shows at a glance the *power* in watts given to the circuit. It consists of a fine wire (volt) coil pivoted close to a fixed thick wire (current) coil, the latter connected in series with one of the mains, the former across them. The action of one on the other causes the moving fine wire coil to deflect by an amount proportional to the watts given to the circuit in which it is placed.

Electricity-meters are instruments having continuously moving parts, by means of which the total amount of power supplied in a given time is recorded on dials like those of a gas-meter. Space will not permit of a further description of such instruments here, but a detailed description of all the many forms of the various types of am-, volt-, watt-, and electricity-meters used in this country and abroad will be found in Parr's 'Electrical Engineering Measuring Instruments,' to which the reader is referred for further information.

CHAPTER VII

ELECTRIC CABLES, ETC.

Electric Cables—Varieties of Cable Construction—Size of Cable for a given Current—Details of Conductors—Aërial Cable—Insulators—Carrying Cable down Shaft, and in Underground Workings.

THE selection of a substance to act as a conductor of the electric current is largely governed by the resistance which it offers to the passage of that current.

The resistance offered by a conductor may be likened to the resistance to the air current in the passages of a mine—*i.e.*, it varies directly as the length and inversely as the sectional area,[1] and just as the coefficient of friction (or resistance for unit area and unit rubbing surface) in a mine varies with the nature of the roads, so the specific resistance (which is the resistance for unit length and unit area) of a conductor varies with the material of which it is composed.

The specific resistance of a substance is the resistance of a length of 1 centimètre with an area of 1 square centimètre at a temperature of 0° C. (32° F.). The specific resistance varies directly with the temperature, but in ordinary ranges of temperature this variation is not very large. The resistance of pure copper rises with the temperature ·238 per cent. per degree F. or ·428 per cent. per degree C.[2]

SPECIFIC RESISTANCE OF METALS.

Name	Specific Resistance in Microhms
Silver annealed	1·468
Silver hard-drawn	1·620
Copper annealed	1·561
Copper hard-drawn	1·621
Aluminium annealed	2·665
Zinc annealed	5·751
Iron annealed	9·065
Tin annealed	13·048
Lead annealed	20·38
Mercury liquid	94·07

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[1] This applies to all conductors built up of small wires; but in the case of solid bars, when sections of copper of ¾ inch diameter are reached, there is, when dealing with alternating currents, a slight percentage to be deducted; over 1 inch diameter, the deduction becomes more important.

[2] *Electrical Engineering Testing*, by G. D. A. Parr.

Having given the specific resistance of a conductor, we can find the total resistance for a given length and area because

$$\text{Total resistance in microhms} = \frac{\text{length in centimètres} \times \text{specific resistance}}{\text{area in square centimètres}}$$

$$1 \text{ microhm} = \tfrac{1}{1000000} \text{ ohm}$$

$$1 \text{ foot} = 30{\cdot}4799 \text{ centimètres}$$

$$1 \text{ square inch} = 6{\cdot}4516 \text{ square centimètres.}$$

Then

$$\text{Total resistance in microhms} = \frac{\text{length in feet} \times 30{\cdot}4799 \times \text{specific resistance}}{\text{area in square inches} \times 6{\cdot}4516},$$

$$\text{and total resistance in ohms} = \frac{\text{length in feet} \times 30{\cdot}4799 \times \text{specific resistance}}{\text{area in square inches} \times 6{\cdot}4516 \times 1{,}000{,}000}$$

$$= \frac{\text{length in feet} \times \text{specific resistance} \times {\cdot}000004724}{\text{area in square inches}}.$$

The material usually employed for conductors is copper, although under certain conditions other metals, such as iron and aluminium, are employed, chiefly in overhead or aërial lines. If we consider the following table—

	Specific Resistance	Specific Gravity
Copper	1·561	8·889
Aluminium . . .	2·665	2·67
Iron	9·065	7·80

—we see that for equal lengths to offer the same resistance to the passage of a current the area of an aluminium cable would have to be $\frac{2{\cdot}665}{1{\cdot}561}$, or 1·7 times the area of a copper cable, and an iron cable $\frac{9{\cdot}065}{1{\cdot}561}$, or 5·8 times the area, while the aluminium cable would be $\frac{1{\cdot}7 \times 2{\cdot}67}{8{\cdot}889} = 0{\cdot}51$ times the weight, and the iron cable $\frac{5{\cdot}8 \times 7{\cdot}8}{8{\cdot}889} = 5{\cdot}1$ times the weight of the copper cable.

The present price of copper cables uninsulated is about 10*d.* per lb., while aluminium rods are 1*s.* 8*d.* per lb. and iron rods 1*d.* per lb., so that, comparing conductors of the same conductivity, the relative cost is—Copper 1, aluminium 1, and iron ·5.

The tensile strengths are—

Hard-drawn copper, about 58,240 lbs. per square inch.
Hard-drawn aluminium, about 25,000 to 30,000 lbs. per square inch.
Iron, about 89,600 lbs. per square inch.

Owing to the great weight of an iron conductor the supporting poles would have to be much stronger than for a copper conductor, and owing to the liability to corrosion it would have to be renewed from time to time.

Aluminium has been used for overhead lines with satisfactory results, although a difficulty in the early application was the joining up of the separate lengths of wire in the line, owing to the electrolytic properties of aluminium when in contact with other metals. The difficulties in joining, however, have been got over by using an oval aluminium tube, into which the two ends are clamped.

Should the price of aluminium fall still further, it will become no doubt a formidable competitor of copper.

If we consider the case of cables covered with insulating material, however, the advantages of copper are considerable. Taking the case of three wires of equal conductivity, it will be seen that the relative diameters will be in the proportion of the square root of their areas, or copper $\sqrt{1}$, aluminium $\sqrt{1.7}$, iron $\sqrt{5{\cdot}8}$, or as $1 : 1{\cdot}3 : 2{\cdot}40$, and consequently the cost of insulating covering would be prohibitive in the case of iron and would render aluminium more expensive than copper at present prices.

In a concentric cable, however, iron has been utilised as a conductor by insulating the copper conductor and surrounding it with an armouring of galvanised wire which acts as the return; but this plan, though it has some advantages, is not now in fashion, as insulated copper returns are preferred.

Sizes of Cables.—The wire of which cables are made is drawn in certain definite sizes or gauges, the leading cable-makers having adopted the standard wire gauge. The sizes of wire used vary from No. 0 S.W.G., which is ·324 inch in diameter, down to No. 25 S.W.G., which is ·02 inch in diameter. These wires are twisted into strands of 7, 19, 37, 61, or 91 separate wires; thus, a cable 19/13 has nineteen wires each of No. 13 S.W.G.

STANDARD WIRE GAUGE.

S.W.G.	Diameter	Area	S.W.G.	Diameter	Area
7/0	0·500	0·196349	11	0·116	0·0105683
6/0	0·464	0·1690931	12	0·104	0·0084949
5/0	0·432	0·146574	13	0·092	0·0066476
4/0	0·400	0·1256637	14	0·080	0·0050265
3/0	0·372	0·108686	15	0·072	0·0040715
2/0	0·348	0·0951149	16	0·064	0·0032170
0	0·324	0·0824479	17	0·056	0·002463
1	0·300	0·0706858	18	0·048	0·0018096
2	0·276	0·0598285	19	0·040	0·0012566
3	0·252	0·0498759	20	0·036	0·0010179
4	0·232	0·0422733	21	0·032	0·0008042
5	0·212	0·0352989	22	0·028	0·0006158
6	0·192	0·0289529	23	0·024	0·0004524
7	0·176	0·0243285	24	0·022	0·0003801
8	0·160	0·0201062	25	0·020	0·0003142
9	0·144	0·0162860	26	0·018	0·0002545
10	0·128	0·0128680	27	0·0164	0·0002112

When the size of the wire happens to be between two of the gauges, the diameter in inches is given; thus, 61/·095 means sixty-one wires each ·095 inch in diameter.

Where a large cable is required it is composed of a large number of small wires, so as to give it greater flexibility than if a small number of large wires were used.

Insulation of Cables.—The material used for insulating the cable is called a di-electric,[1] and the best di-electrics are those which offer the greatest resistance to the passage of an electric current; those most commonly employed are pure rubber, vulcanised rubber, ozokerited tape, and paper or some other material impregnated with oil. The latter cables require to be enclosed in a lead casing to keep all moisture out, and they then possess very high insulative properties. In some cases the copper cable is laid in a pipe full of thick oil. When cables are insulated with vulcanised rubber the wires are invariably tinned to protect them from the action of the sulphur in the vulcanised rubber. Over the tinned wire a layer of pure rubber is often put before the vulcanised rubber is added.

The thickness of the di-electric is increased as the voltage intended to be carried is increased. For high voltages the thickness is $\frac{1}{20}$ inch per 1,000 volts; thus, for a cable carrying 10,000 volts there would be a paper covering $\frac{1}{2}$ inch thick all round, so that if the diameter of the copper was $\frac{1}{2}$ inch the total diameter over the paper would be $1\frac{1}{2}$ inch, and the lead pipe, say, $\frac{1}{8}$ inch or $\frac{1}{6}$ inch thick, makes the total thickness outside the lead pipe $1\frac{3}{4}$ inch to $1\frac{7}{8}$ inch. But for low tensions the thickness of the di-electric is greater in proportion; thus, with a cable made of nineteen wires No. 12 gauge for a pressure up to 500 volts the thickness of vulcanised-rubber insulation would be $\frac{1}{10}$ inch, and the thickness for 2,000 volts would be very little more. For large cables a thicker di-electric is used than for small cables; thus, for a cable 37/12 the thickness of di-electric for 500 volts is ·12 inch, and for 2,000 volts ·14 inch. For a cable 7/23 at 500 volts the thickness of vulcanised-rubber insulation is ·05, and at 2,000 volts ·1. For large cables it is now a common practice to use a paper-covered cable in a lead pipe for the main conductor, while for branch conductors, in a mine, it is common to use vulcanised-rubber insulation.

Having decided how to insulate the cable, the next consideration is how to protect the insulation. In the case of indiarubber insulation, this is generally protected by a wrapping of tape soaked in some waterproofing composition, and this tape is again protected by a covering of jute fibre, called braid, also soaked in waterproofing composition. The cable may now be safely handled, and if placed in a position where it will be free from all rough treatment and from falling water, if not over-worked it should last for a great many years. In answer to inquiries, the makers of indiarubber-insulated cables state that they have had them in work ten years at places where they are still in perfectly good order. But if the cable may be subjected to rough usage, then it is common to protect it with an iron or steel covering. This may be in the shape of a steel tape wrapped round, the steel being coated with some waterproofing material, and afterwards wrapped with jute braiding soaked in tar. In place of steel tape a covering of galvanised wire may be wrapped round, and this is said to be stronger in resisting a blow from a pickaxe than the tape. In some cases the cable is wrapped with a locked coil wire, which makes a very complete armour. For protection against water, india-rubber-covered cables are often covered with lead pipe.

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[1] The term 'di-electric' is, strictly speaking, used to denote the insulation separating the consecutive plates of an electric condenser, but it is a term popularly used in speaking of the insulation of any cable.

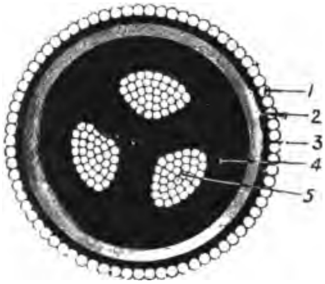
The paper-covered cables, which are always in a lead pipe (the thickness of which, for a cable 3 inches in diameter, is ·185 inch), are often covered outside the lead with a braiding of jute and tar, and then with an armouring of iron tape or wire.

The cables are of the following construction :—

1. Single cable insulated and protected as above described.

2. Twin cables insulated as above, then placed side by side and covered with protecting braiding, tape, lead pipe, armour, &c.

FIG. 80.



THREE-CORE ARMOURED CABLE.

1. Steel wire. 2. Jute. 3. Lead. 4. Insulation. 5. Triangular copper strand.

3. Three cables, either round or of flattened section (see fig. 80), each separately insulated, and then bound together and protected as above.

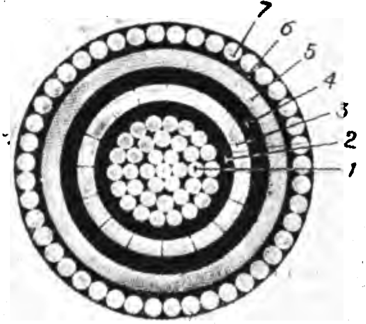
4. Four cables, either round or of flattened section, each separately insulated, and then bound together and protected as above.

5. A concentric cable with internal copper conductor, then insulating material, then copper wire laid in a ring of equal sectional area to the conductor, then insulating material, and protecting covering as above described (see fig. 81).

6. Internal copper cable, then insulation, then a ring of copper wires, then insulation, then a second ring of copper wires, then insulation, and protective covering as before.

In this way three conductors are obtained concentrically. Conductors of this kind have been made with the central cable equal to 1 square inch in section, made up of ninety-one wires each ·118 inch diameter, the two surrounding rings of copper being also of the same sectional area, and the total diameter outside the lead pipe being 3⅛ inches. For use in mines each of the above varieties would sometimes be found applicable.

FIG. 81.



·25 SQ. IN. ARMOURED CONCENTRIC CABLE, BY THE BRITISH INSULATED WIRE COMPANY.

1. Copper strand. 2. Insulation. 3. Copper strips. 4. Insulation. 5. Lead. 6. Jute. 7. Steel wire.

When three conductors are bound together in one cable either side by side or concentrically, it is not necessary that each conductor should be equal in section to the others ; if the three-wire system is adopted, one might be half the size. Sometimes a small conductor is laid in the space between two of the larger conductors.

The limit to the length of cable made in one piece is the size and weight of the drum covered with cable that can be conveniently handled.

The lead covering above referred to is made a tight fit to the cable in the following way : The cable to be covered is drawn through a nozzle which fits it ; over this nozzle, and surrounding it, is another one of larger size, the space between being equal to the intended thickness of lead ; into this annular nozzle, lead in a soft, half-melted state is forced by hydraulic pressure, the temperature not being sufficiently high to damage the insulating material of the cable. The cable before leaving the works is tested to see that the insulation is perfect at the required voltage.

Rules for Size of Cable for a Given Current.—By Ohm's Law $C = \frac{E}{R}$ where C is the current in ampères, E is the E.M.F. in volts, and R is the resistance in ohms; from which we get $E = CR$, or the volts expended in sending a current of C ampères through a conductor of R ohms' resistance are equal to the product of the current and the resistance.

The power as measured in watts $= E \times C$, and the horse-power is shown by the rule: $\text{h.p.} = \frac{E \times C}{746}$. Substituting the value of E, as found above, we get

$$\text{watts} = C\,R \times C = C^2R$$

and

$$\text{h.p.} = \frac{C\,R \times C}{746} = \frac{C^2R}{746}.$$

Thus the horse-power lost in the cable varies *directly as the square of the current, and directly as the resistance.*

This horse-power is, of course, represented by a rise in temperature of the cable, which fact governs the maximum loss allowable.

With the current density at 1,000 ampères per square inch, the loss in voltage is approximately $2\frac{1}{2}$ volts per 100 yards. With a current of 800 ampères per square inch the drop is 2 volts per 100 yards. The question of size of cable required is also dealt with in Chapter VIII.

The following diagram (fig. 82) is copied from one lent to the authors by Messrs. W. T. Glover & Co., electric-cable makers, and has been prepared by Mr. A. H. Howard. It is very interesting, because it shows at a glance the current in ampères that can be carried by a conductor of any given size between $\frac{1}{1000}$ square inch in sectional area and 1 square inch in sectional area, at varying fall of potential per 100 yards from $\frac{1}{10}$ volt up to 6 volts, and it gives the rise of temperature in degrees Fahrenheit for a drop of voltage per 100 yards varying from 1 volt up to 6 volts.

The diagram shows graphically dimensions and fall of potential and approximate rise of temperature of any wire with any current.

Directions for Using.

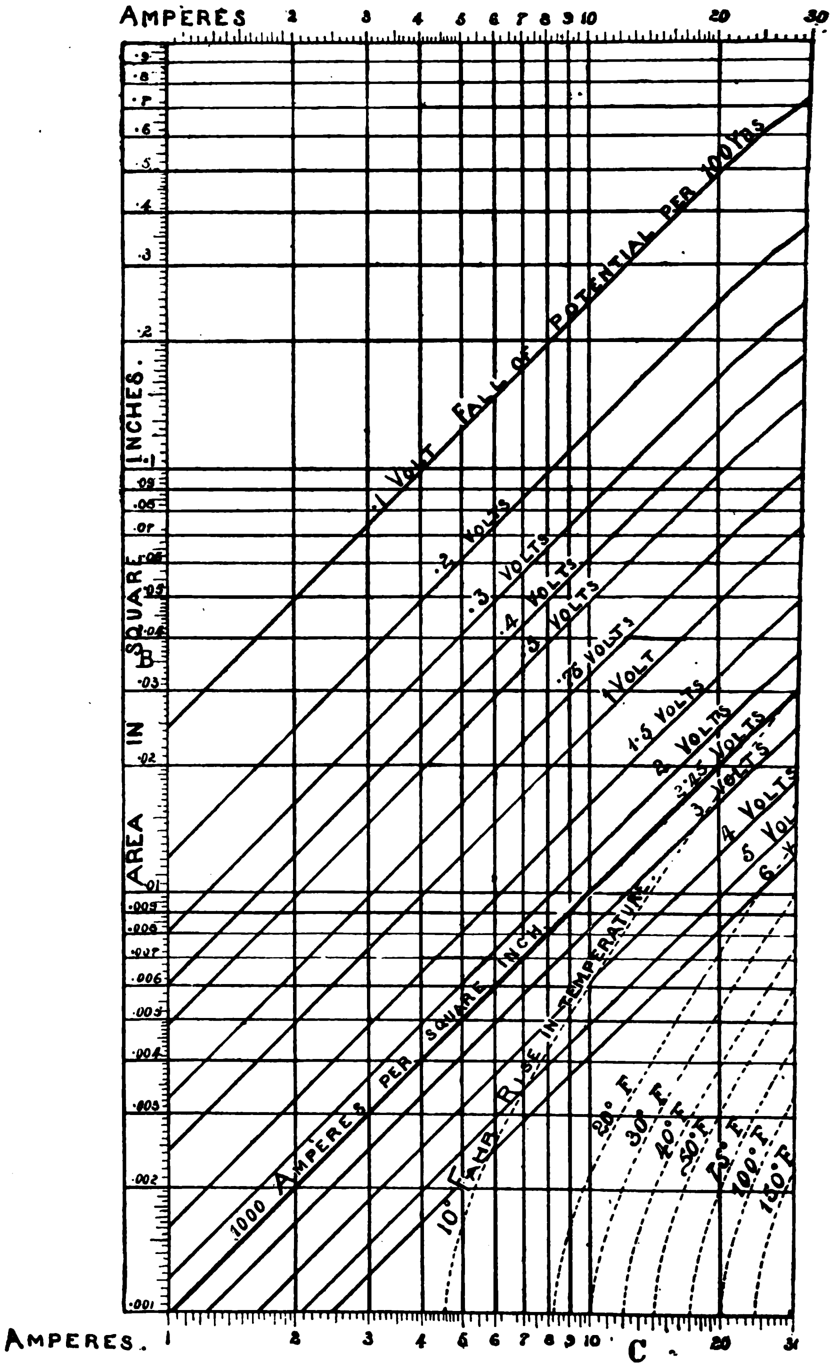
The horizontal lines represent areas or sizes of wires, as shown in the vertical columns.

The vertical lines represent current in ampères, as numbered at the top and bottom.

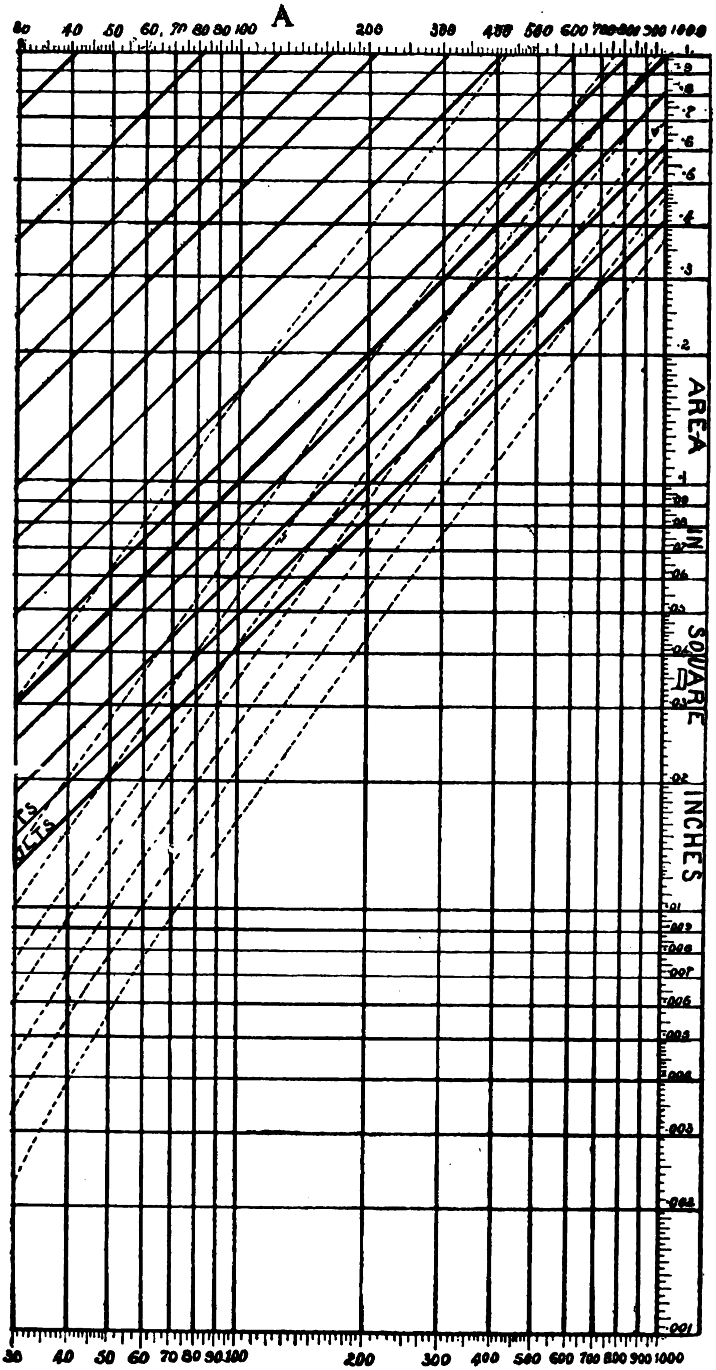
The black diagonal lines represent fall of potential per 100 yards of single cable.

The dotted black curves represent approximate rise of temperature of insulated wires in wooden casing, as ascertained by experiments in the Edison Laboratory.

FIG.



FALL OF POTENTIAL AND RISE IN



Temperature for any Conductor.

If any two of the above quantities are given, the other two are found at a glance by the lines passing through the point of intersection of the two lines representing the known data.

Example.—To run a current of 60 ampères, with a fall of potential of 2 volts per 100 yards. Required, size of cable and rise of temperature.

The vertical line 60 intersects the diagonal for 2 volts per 100 yards at a point on the horizontal line opposite ·074 in the area column. The cable nearest in area (see following table) to this is a 7/11. The dotted curve for 10° F. is just above the point; consequently, the rise in temperature is about 11° F.

The following table, extracted from the list of the above-named makers, gives the sizes of copper wires and cables according to the standard gauge :—

Details of Conductors.

Showing Dimensions, Capacity, Resistance, and Weight.

Size	Diameter		Area		Standard Resistance at 60° F.	Standard Weight	
S.W.G.	Inches	Millimètres	Square Inches	Square Millimètres	Ohms per 1,000 Yards	Pounds per 1,000 Yards	Pounds per Mile
22	·028	0·7112	·0006158	·3973	39·05	7·120	12·53
21	·032	0·8128	·0008042	·5188	29·90	9·301	16·37
20	·036	0·9144	·001018	·6567	23·62	11·77	20·72
19	·040	1·016	·001257	·8109	19·13	14·53	25·58
18	·048	1·219	·001810	1·168	13·28	20·93	36·83
17	·056	1·422	·002463	1·589	9·762	28·48	50·12
16	·064	1·626	·003217	2·075	7·478	37·20	65·47
15	·072	1·829	·004072	2·627	5·904	47·09	82·87
14	·080	2·032	·005027	3·243	4·784	58·13	102·3
13	·092	2·337	·006648	4·289	3·617	76·88	135·3
12	·104	2·642	·008495	5·480	2·831	98·24	172·9
11	·116	2·946	·01057	6·819	2·275	122·2	215·1
10	·128	3·251	·01287	8·303	1·868	148·8	261·9
9	·144	3·658	·01629	10·51	1·476	188·4	331·5
8	·160	4·064	·02011	12·97	1·195	232·5	409·2
7	·176	4·470	·02433	15·70	·9881	281·3	495·1
6	·192	4·877	·02895	18·68	·8307	334·7	589·1
5	·212	5·385	·03530	22·77	·6813	408·2	718·4
4	·232	5·893	·04227	27·27	·5688	488·8	860·2
3	·252	6·401	·04988	32·18	·4821	576·7	1015·0
2	·276	7·010	·05083	38·60	·4019	692·0	218·0
1	·300	7·620	·07069	45·60	·3402	817·6	1439·0
1/0	·324	8·230	·08245	53·19	·2917	953·4	1678·0
2/0	·348	8·839	·09511	61·36	·2528	1099·0	1935·0
3/0	·372	9·449	·1087	70·13	·2212	1257·0	2212·0
4/0	·400	10·16	·1257	81·09	·1913	1453·0	2558·0
5/0	·432	10·97	·1466	94·58	·1640	1695·0	2983·0
6/0	·464	11·79	·1691	109·1	·1422	1955·0	3441·0
7/0	·500	12·70	·1963	126·6	·1225	2270·0	3995·0

Details of Conductors.

Showing Dimensions, Capacity, Resistance, and Weight.

Size	Diameter of each Wire		Effective Area—v z., Area of Solid Wire having same Conductivity		Standard Resistance at 60° F.	Standard Weight per Mile
S.W.G.	In Inches	In Millimètres	Square Inches	Square Millimètres	Per 1,000 Yards	Lbs.
3/25	·020	·5080	·0009311	·6007	25·82	19·42
3/24	·022	·5588	·001127	·7271	21·33	23·49
3/23	·024	·6096	·001341	·8651	17·94	27·96
3/22	·028	·7112	·001825	1·177	13·18	38·05
3/21	·032	·8128	·002384	1·538	10·09	49·71
3/20	·036	·9144	·003016	1·946	7·972	62·92
3/19	·040	·1016	·003725	2·403	6·455	77·68
3/18	·048	·1219	·005364	3·461	4·482	111·8
7/25	·020	·5080	·002177	1·404	11·05	45·23
7/24	·022	·5588	·002633	1·699	9·131	54·71
7/23	·024	·6096	·003135	2·023	7·670	65·12
7/22	·028	·7112	·004266	2·752	5·636	88·63
7/21½	·030	·7620	·004896	3·159	4·910	101·8
7/21	·032	·8128	·005571	3·594	4·316	115·8
7/20½	·033	·8382	·005925	3·822	4·059	123·2
7/20	·036	·9144	·007052	4·550	3·410	146·6
7/19	·040	1·016	·008708	5·618	2·761	180·9
7/18	·048	1·219	·01254	8·090	1·918	260·5
7/17	·056	1·422	·01706	11·01	1·410	354·5
7/16	·064	1·626	·02227	14·37	1·080	463·1
7/15	·072	1·829	·02822	18·21	·8523	586·2
7/14	·080	2·032	·03483	22·47	·6903	723·6
7/13	·092	2·337	·04605	29·71	·5222	957·1
7/12	·104	2·642	·05884	37·96	·4086	1223·0
7/11	·116	2·946	·07322	47·24	·3284	1522·0
7/10	·128	3·251	·08917	57·53	·2697	1853·0
7/9	·144	3·658	·1129	72·84	·2131	2345·0
7/8	·160	4·064	·1393	89·97	·1726	2894·0
7/6	·192	4·877	·2006	129·4	·1199	4167·0
19/22	·028	·7112	·01157	7·464	2·079	240·8
19/21	·032	·8128	·01510	9·742	1·592	314·6
19/20	·036	·9144	·01912	12·34	1·257	398·3
19/19	·040	1·016	·02360	15·23	1·019	491·7
19/18	·048	1·219	·03399	21·93	·7074	707·9
19/17	·056	1·422	·04627	29·85	·5197	963·3
19/16	·064	1·626	·06039	38·96	·3981	1258·0
19/15	·072	1·829	·07650	49·35	·3143	1593·0
19/14	·080	2·032	·09442	60·91	·2547	1966·0
19/13	·092	2·337	·1249	80·58	·1926	2601·0
19/12	·104	2·642	·1595	102·9	·1507	3323·0
19/11	·116	2·946	·1985	128·1	·1211	4134·0
19/10	·128	3·251	·2417	155·9	·09949	5034·0
37/20	·036	·9144	·03722	24·01	·6460	775·8
37/19	·040	1·016	·04596	29·65	·5232	957·9
37/18	·048	1·219	·06619	42·70	·3633	1379·0
37/17	·056	1·422	·09006	58·10	·2670	1877·0
37/16	·064	1·626	·1176	75·87	·2045	2451·0
37/15	·072	1·829	·1489	96·06	·1615	3103·0

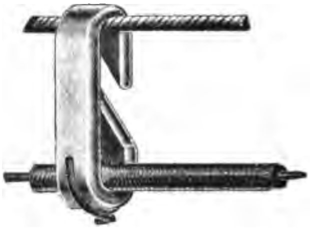
DETAILS OF CONDUCTORS—*continued.*

Size	Diameter of each Wire		Effective Area—viz., Area of Solid Wire having same Conductivity		Standard Resistance at 60° F.	Standard Weight per Mile
S.W.G.	In Inches	In Millimètres	Square Inches	Square Millimètres	Per 1,000 Yards	Lbs.
37/14	·080	2·032	·1838	118·6	·1309	3830·0
37/13	·092	2·337	·2431	156·8	·09892	5066·0
37/12	·104	2·642	·3105	200·3	·07744	6474·0
61/18	·048	1·219	·1091	70·38	·2204	2274·0
61/17	·056	1·422	·1485	95·80	·1619	3094·0
61/16	·064	1·626	·1939	125·1	·1240	4042·0
61/15	·072	1·829	·2455	158·4	·09795	5116·0
61/14	·080	2·032	·3029	195·4	·07937	6316·0
61/13	·092	2·337	·4008	258·6	·06000	8353·0
61/12	·104	2·642	·5120	330·3	·04697	10674·0
91/14	·080	2·032	·4519	291·5	·05320	9442·0
91/13	·092	2·337	·5977	385·6	·04023	12462·0
91/12	·104	2·642	·7638	492·8	·03148	15925·0
91/11	·116	2·946	·9504	613·1	·02530	19811·0

Erection of Cables, &c., on Surface.—The cables on the surface may be carried on wood or iron poles, with cross bearers at the top, to which insulators are attached. As there is not the same danger of persons coming in contact with them as when in the confined passages of a mine, and also not the same liability to damage, the insulation on these overhead cables need not be so heavy (or they may be bare), provided that the points where they are supported are efficiently insulated so as to prevent the current getting to 'earth.'

The distance apart of the supporting poles depends on the weight of the cable, but by the use of a steel wire strained between the poles to hang the cable to, the distance between the poles may be increased. The cable suspenders may be made of leather, porcelain, &c.; one form is shown in fig. 83.[1]

FIG. 83.



CABLE SUSPENDER.

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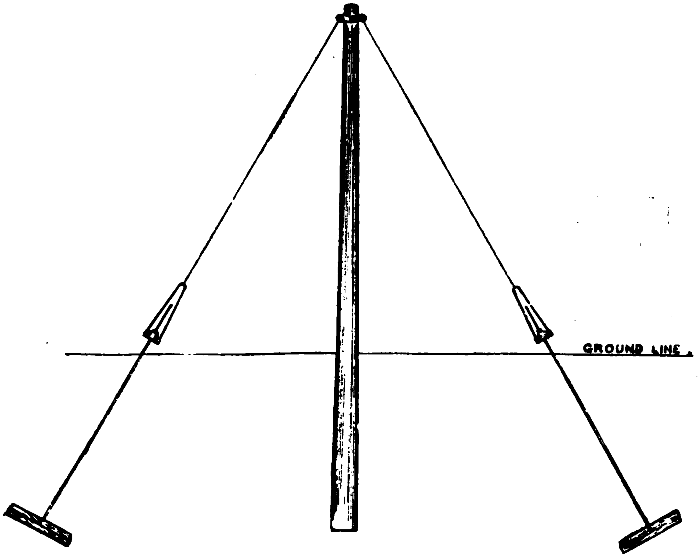
[1] Fawcus and Cowan's Patent.

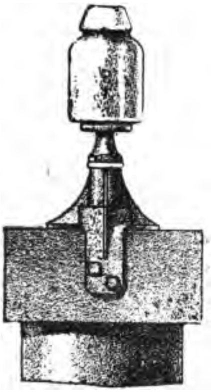
For mining purposes in countries where there is no liability to the attacks of destructive insects, &c., wood poles form the best support to the cable; these should be creosoted or otherwise treated so as to preserve them.

Fig. 84



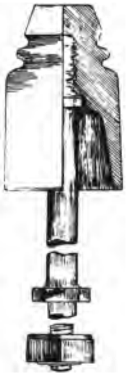
Pole to Carry Aërial Line.

Fig. 85.



Pole Roof, Insulator Bracket and Insulator.

Fig. 86.



Single-shed Insulator.

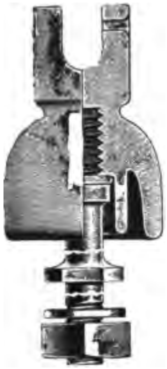
The method of fixing a pole is shown in fig. 84. The stay rods shown are required in exposed situations; they are not always used.

The cable, if carried on the top of the pole, is held in a bracket as shown in fig. 85, and the top of the pole is covered with a zinc roof.

The insulators may be of brown ware or porcelain; the latter has the higher insulation resistance.

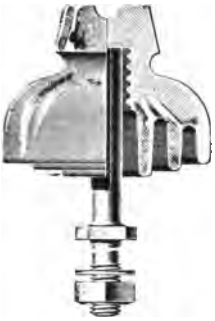
The resistance of porcelain is so high that a leakage of current cannot take place through it, but takes place over the surface when the latter is wet or dirty. For this reason the type of insulator employed varies with the tension or voltage employed.

Fig. 87.



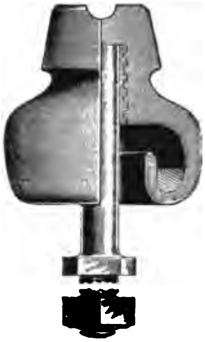
Double-shed Insulator.

Fig. 88.



Triple-shed Insulator.

Fig. 89.



Fluid Insulator.

Fig. 86 illustrates a single-shed insulator for low-tension lines.

Fig. 87 illustrates a double-shed insulator, in which it will be seen that there is a much greater surface over which the electricity must leak, and, as this extra surface is also kept dry, it offers a greater resistance on that account.

Fig. 88 shows a triple-shed insulator, and fig. 89 shows a fluid or oil insulator, in which oil is placed in an annular groove to intercept the leakage of electricity over the surface.

Where it is not possible or desirable to carry the cable on poles, it may be laid down in a trough or pipe (see Callender's system, page 131).

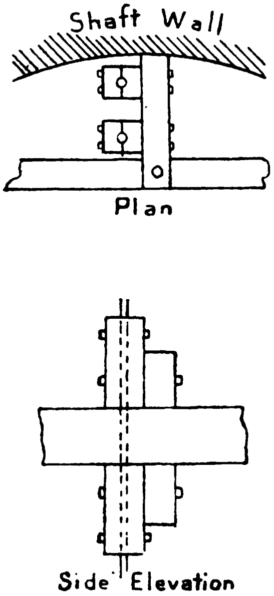
Distribution of Electric Current in Shafts and Workings.—The most common method of carrying electric current down a shaft is no doubt to enclose both cables side by side in a hard-wood casing, and in many cases this is found perfectly satisfactory. This casing need not be continuous, but may take the form of wooden clamps as shown in fig. 90.

Where the shaft is inclined to be wet, however, this method is open to serious objection owing to the insulation becoming defective.

At the Ackton Hall Colliery the cables are suspended from the top of the pit without any intermediate support.[1]

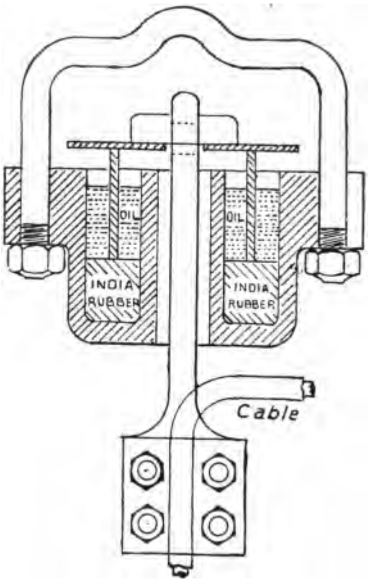
A patent oil insulator is used, which consists (fig. 91) of an annular cast-iron vessel with a lug on each side, by means of which it can be suspended. At the bottom of the annular space is a thick ring of india-rubber, on which rests the support that carries the weight of the cable.

FIG. 90.



CARRYING CABLE DOWN SHAFT IN WOOD CASING.

FIG. 91.



HOLIDAY'S OIL INSULATOR.

The remainder of the space is filled with creosote oil, and the cable is held by an ordinary wrought-iron rope clamp.

The cables suspended in this way have been found satisfactory.

Owing to there being only one point of contact with the shaft, and that a very efficient insulator, there is no need for the cable to be heavily insulated, a light covering only being necessary, sufficient to prevent a person getting a shock by accidentally touching the cable.

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[1] 'Electricity at Ackton Hall Colliery,' by H. St. John Durnford and Roslyn Holiday; *Transactions Institution of Mining Engineers*, xiii. 232.

The cost of putting in one of these cables is given by the authors of the paper as follows:—

One thousand one hundred yards 19/16 1,000 megohms cable, £73 6*s.*; two oil insulators, 12*s.*; four workmen, each half a day, 10*s.* 6*d.*; one engineman half a day, 3*s.* 4*d.*; total £74 11*s.*

The only strain on the cable is its own weight, and at a great depth armouring of galvanised iron wire is employed which increases the factor of safety. The following tests on the strength of copper cables have been made for the authors by Mr. G. F. Charnock, head of the Engineering Department of the Technical College, Bradford, on samples kindly supplied by the St. Helens Cable Company, Warrington :—

TENSILE TESTS OF SAMPLES OF COPPER CABLE.

Each cable 3 feet long, prepared with conical ends of soft metal alloy and held in conical dies. The area of a 61/110 cable is about 0·58 square inch.

Size	Weight per Mile	Description	Breaking Strength	Remarks
	Lbs.			
61/110	12,000	Soft-drawn bare copper cable	8·04	Broke close to bottom die, equivalent to 13·8 tons per sq. in.
61/110	27,100	Soft-drawn armoured with galvanised wire . .	18·78	Broke clear of die

It was found that hard-drawn copper cables could not be tested in this way, as the casting on of the conical end seemed to exercise an annealing effect on the hard-drawn wire. Several hard-drawn wires, however, from a 61/110 cable, were tested separately, and the average breaking-strength was found to be 500 lbs., which is equivalent to a strength for hard-drawn copper of 23·5 tons per square inch.

The tensile strength of soft copper varies greatly, 14 tons[1] per square inch being the usual figure for soft copper and 32 tons per square inch for hard-drawn copper. The elongation of soft wire is often 25 per cent., so that it is not employed where there is liability to great strain, the hard wire being then employed, which has an elongation of 2 or 3 per cent. Hard-drawn wire is not so flexible or easily handled as soft-drawn wire, and if insulated it is apt to injure the insulation if it gets kinked. Where very great strength is required in a conductor, therefore, an additional medium should be supplied, such as an iron or steel armouring.

In the case of a deep dry shaft, where it is proposed to enclose the cables in wood casing, it is advisable to take the weight off the cable as far as possible, and this can be easily done by making the groove in a gentle curve at intervals (see fig. 92).

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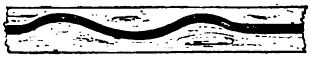
[1] These figures are supplied by the Indiarubber, Guttapercha, and Telegraph Works Company, Limited.

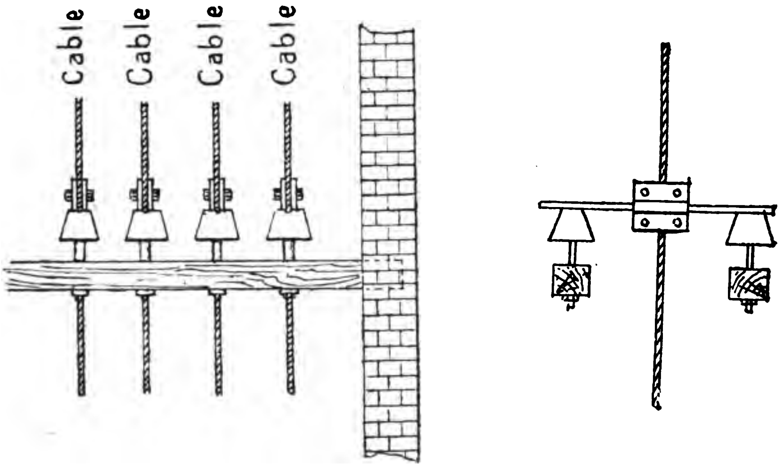
FIG. 92.



WOOD CASING, WITH CURVED GROOVE.

Another plan, employed at the Middleton Colliery, near Leeds, is to fasten clams on to the cable; the clams rest on pole insulators supported by two bearers, as shown in fig. 93. In a shaft 160 yards deep there are one set of these at the top and two at intermediate places in the shaft, and at the bottom the cables are secured to shackle insulators, there being no weight to carry at this point. The cables are not armoured, but have the usual insulation.

FIG. 93.



METHOD OF SUPPORTING CABLES AT MIDDLETON COLLIERY.

At the St. John's Colliery (Normanton)[1] the cables in the shafts are lead covered, and originally hung in the shaft without other covering, but pieces of coal falling from the tubs punctured the lead and great leakage ensued, and the cables are now enclosed in wooden boxes nailed to the stays. At intervals of about 150 feet, a piece is scooped out of the box about the size of a hen's egg, and at that point a swelling is worked on the cable by tape and varnish, and thus the cables are supported and the arrangement works satisfactorily.

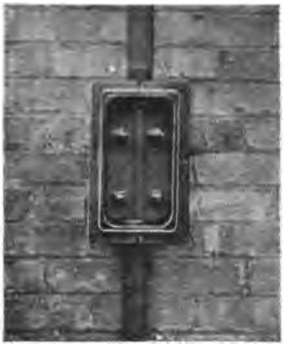
---

[1] 'Electricity at Ackton Hall Colliery'; discussion by Mr. E. Brown.

Another method of supporting the cable in a shaft is to tie it to insulators spaced, say, 10 yards apart in the shaft, the loop of the cable being taken round a large insulator at the top of the shaft.

Another method is to enclose the cables in iron pipes and run in melted pitch to completely fill up the space. Where the cables are run in pipes they may be supported by a clamp contained in a box, as shown in fig. 94.[1]

FIG. 94.



METHOD OF SUPPORTING CABLE IN SHAFT.

Carrying Cables in the Workings.—The most usual plan of carrying the cables in the mine is to have one on each side of the road and hang them loosely between the insulators. By this means any fall of the roof catching the cable would pull up the slack in the cable without causing a fracture.

Fig. 95 shows three forms of insulator very commonly used, the cable being secured to the insulator by a piece of yarn.

Mr. Robert Hay, of Stanton Colliery, Burton-on-Trent, has designed and patented the pot insulator shown in fig. 96. This is a useful form, and the cable is very expeditiously laid along the road.

Fig. 97 shows a method of supporting a cable by a piece of galvanised wire hung on to a nail. The cable in this case is a concentric one with a bare return, so that insulators would not be needed.

In main roads the cables are sometimes buried where there is no danger of the insulation being corroded. Mr. Maurice Deacon[2] carries out this principle by placing three-phase cables in a puddled-clay trench in the middle of the road on an engine plane in a steep place. The cables employed are well armoured and waterproofed.

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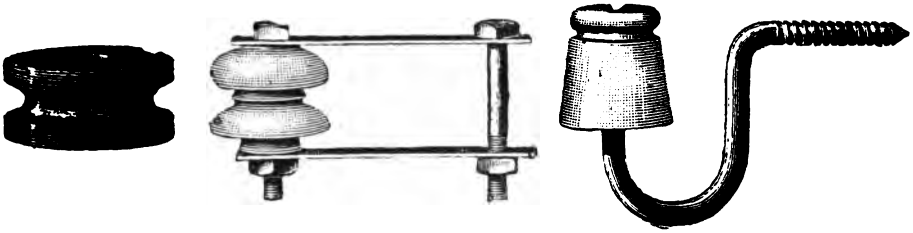
[1] This method is used by Messrs. John Davis & Sons, Derby.

[2] *Trans. Fed. Inst. M.E.* xxii. 264 *et seq.*

The importance of covering up the cables in a road which is being repaired should also be realised.

FIG. 95.

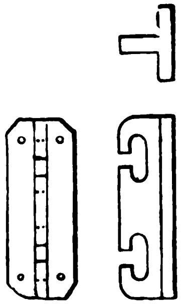


VARIOUS TYPES OF INSULATORS.

In main roads which have been driven some time, and in which all movement of the strata has subsided, the cables may be laid in a more permanent manner on Callender's system (see figs. 98 and 99).

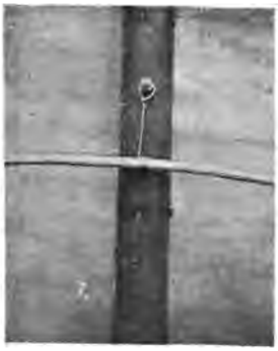
Earthenware, wood, or metal troughing is used in which to lay the cable, which is supported at intervals on bituminised wood bridges, and the trough is then run in solid with bitumen. The cables used in connection with this system are insulated with vulcanised bitumen sheathing, and the only conductor of electricity in the cable is its copper core. The makers claim that it is impossible for leakage currents or stray earth return currents to get to the sheathing, as is the case with a lead-covered cable.

FIG. 96.



HAY'S PATENT INSULATOR.

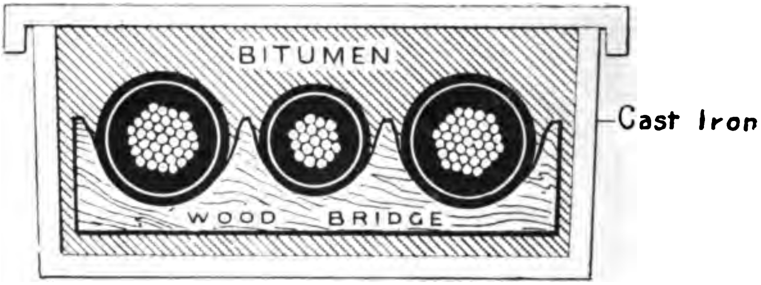
FIG. 97.



METHOD OF CARRYING CABLE ON UNDERGROUND ROAD.

The bitumen has, of course, to be melted, and this forms a possible drawback to the use of this system in the roads of a mine, although there will no doubt be many mines where the system could be used.

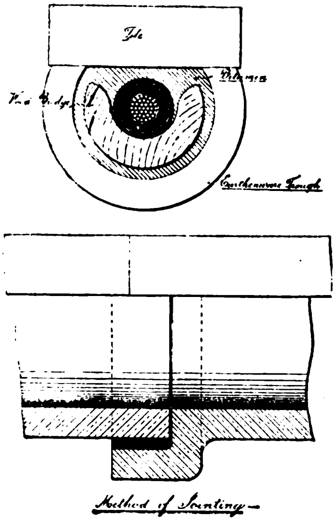
FIG. 98.



CALLENDER'S SYSTEM OF LAYING CABLES IN CAST-IRON TROUGH.

It is convenient in a long length of cable to have it divided up into sections, as by this means the testing of the cable is greatly expedited.

FIG. 99.

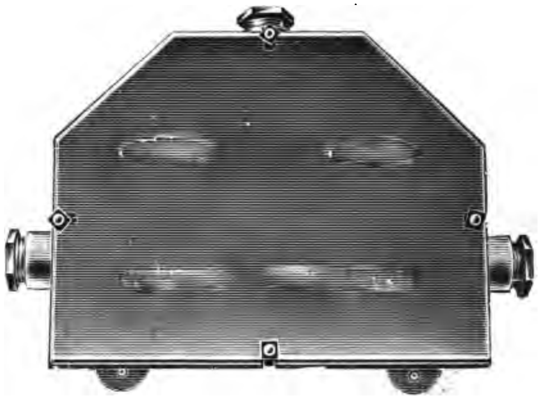


CALLENDER'S SYSTEM OF LAYING CABLES IN EARTHENWARE TROUGH.

At each of these sections the cables would be enclosed in a gas-tight junction box securely fastened. A cut-out might also be placed in the box.

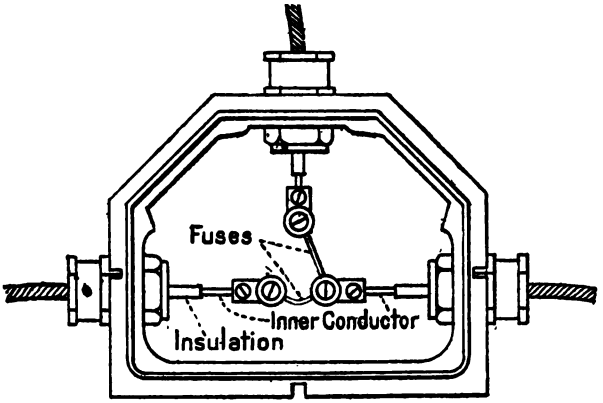
Figs. 100 and 101 show a three-way junction and fuse box made by Messrs. John Davis & Son, Derby; it will be seen that the cables are con-

FIG. 100.



CAST-IRON JUNCTION BOX.

FIG. 101.



THREE-WAY CAST-IRON JUNCTION AND FUSE BOX, WITH COVER REMOVED.

centric, with galvanised outer conductor, and that the outer conductors are connected to the iron box, but the inner copper conductors are insulated from it. A good method of making a gas-tight entrance for a cable into a junction or switch box is shown in fig. 102.[1]

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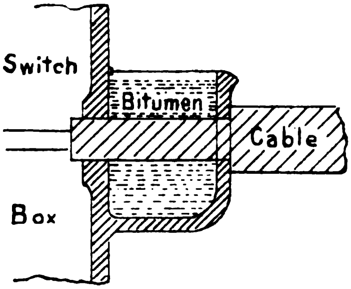
[1] 'Electric Haulage at Manvers Main Colliery,' by A. T. Thompson; *Transactions Institution of Mining Engineers*, xx. 29.

Safety Cables.—From time to time various safety cables have been introduced, and although some of these are very ingenious, there are none in use at the present time, as experience in electrical transmission of power at collieries has shown that they are not necessary. A description of some of these safety cables will be interesting, as no doubt the matter is one which often occurs to the colliery manager who is putting down an electrical installation.

A safety concentric cable was introduced by Messrs. Clarke, Chapman & Co. in 1892 with a view to preventing an explosion, owing to the sparking taking place between the two ends of a cable when fractured.

The principle on which the arrangement depends consists in conveying a small portion of the current in separate wires insulated from the rest of the conductors throughout the whole length of the cable, and of so arranging them that in case of an accident, such as a fall of the roof or a tub getting off the rails, this small cable would be most likely to get broken; but as it only carries a small portion of the current there would be no dangerous sparking, and the result of the fracture would be immediately to break the circuit by means of an electro-magnetic device.

FIG. 102.



CABLE ENTERING SWITCH BOX.

In Atkinson's safety cable [1] the current is also carried in two conductors insulated from each other, and in each of which is a cut-out. The outer one is designed to carry the larger part of the current, and the inner one is made of fine wire in the form of a continuous cylindrical coil, the outer diameter of which is covered by insulation, and forms the core round which the main conductor is laid.

The theory is that a stone falling on the cable might cut through the outer conductor, but the inner conductor would stretch and not break, so that the entire current would be passing through the small conductor, and would fuse its cut-out. A weight would then be released and fall on to a switch, closing the main circuit.

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[1] *Electric Motive Power*, by Albion T. Snell.

CHAPTER VIII

CENTRAL ELECTRICAL PLANTS

Central Electrical Plants for Winding, Ventilating, Pumping, Hauling, Coal-cutting, Workshops, Screens, &c.—Comparison of High and Low Voltage as affecting Cost of Cables—Three-wire System—Estimates of Cost.

DURING the last few years Acts of Parliament and Orders in Council have been obtained, authorising large central electric power stations, intended to distribute electric power over whole counties, such as the Derbyshire and Nottinghamshire Electric Power Act, 1901; the Yorkshire Electric Power Act, 1901; the Lancashire Electric Power Act, 1900; the South Wales Electric Power Act, 1900; the South Staffordshire Mond Gas Act, 1901, and the Cornish Electric Power Act, 1902. It is intended under these Acts to put up central electric stations, each containing, say, from 5,000 up to 50,000 h.p. When these come into work the power obtained from these stations may be used by mining engineers, and so save them from the necessity of erecting their own electric generating stations. But in the meantime, engineers are erecting central generating stations at mines, intended to supply the power required for most of the machines at one mine. At a colliery there are often thirty or forty small steam-engines, nearly all of them of wasteful construction and wastefully used, and the intention is to supersede these small steam-engines by electric motors, the electricity being generated by either steam- or gas-engines which use fuel in the most economical way. In order to understand how such electric transmission can be economical, the great difference in the steam consumption per I.H.P. in various classes of engine must be considered. With steam at 180 lbs. pressure per square inch with triple-expansion condensing reciprocating engines, 12 lbs. of steam will generate 1 I.H.P. for an hour. A small steam-engine, as commonly used at a colliery, with a long length of steam-pipe from the boilers, will probably use at least ten times as much steam per I.H.P., or 120 lbs., and this quantity is probably greatly exceeded in many cases. The average at a colliery of all the engines, big and little, is probably, where more than average attention is given to steam economy, about 80 lbs. of steam per I.H.P. There is here a great margin for economy. Assuming that the combined efficiency of the generating steam-engine and dynamo is only 70 per cent., and that of the motor is 80 per cent. (these low efficiencies being taken to allow for working at small fractions of the full power on the one hand, and at excessive powers on the other hand, and also for loss when running without load), and the loss in the conductor is 5 per cent., we have the following result: $\frac{70}{100} \times \frac{80}{100} = \frac{56}{100}$; and deducting 5 per cent. of 70, or 3·5, we get 52·5 per cent. of the engine-power delivered on to the machine. It will, however, be advisable to make further allowance for loss on small conductors and contingencies equal to, say, 5 per cent. of the engine-power, thus reducing the net efficiency to 50 per cent. The amount of steam, therefore, required per h.p. on the machine will be as 50 : 100 : : 12 : 24. It would not, however, be wise to assume that the engine of the electric generating plant would always work at the very high efficiency of 12 lbs. of steam per I.H.P.; but we might safely assume that the consumption would not exceed 20 lbs. per I.H.P., and at that rate the cost of steam power on the machine in pounds of steam per I.H.P. hour would be as 50 : 100 : : 20 : 40. By this means the fuel consumption should be brought down to, say, half or one-third of what it is with ordinary steam-engines and long-distance steam transmission.

The question, however, that next arises is the extent to which electric motors are applicable in the case of large engines, such as winding, pumping, and hauling engines. We may say as a general rule that the electric motor is applicable to all small engines, and to large engines which run continuously, such as fan engines and pumping engines; but when we come to hauling and winding, the advantage or otherwise of electrical driving requires special consideration in each case. If the haulage is done by endless rope or chain, it is practically continuously working for eight or ten hours a day at a uniform speed, and then the electric motor would be eminently suitable. If the haulage is at high speeds, and continually starting and stopping, the advantage of the electric motor is less apparent, but still in most cases it might be used with economy.

The large colliery winding-engine stands by itself, and as a general rule it may be said that it is not practicable in this case to substitute an electric motor for the steam-engine.

These engines work up to 1,000 and even 1,500 h.p., but this high power is only continued for a few seconds. The cycle of work in a winding engine is as follows: It is started, gradually increases in speed, reaches its highest power, has its speed gradually reduced, and is brought to rest within one minute, and if it were driven from a central electric station the generators at that station would have to be equal to this sudden strain and equally sudden stoppage; and it would probably pay the mining engineer better to endeavour to make the steam winding-engine economical than to substitute an electric motor for it. In the case of small winding-plants the matter is different. A central station which would not be equal to supplying 1,000 h.p. at five seconds' notice might easily supply an extra 50 or 100 h.p. for a few seconds. It is possible that some day continuously working lifts may be substituted for the ordinary colliery winding-engine, and for such lifts electric transmission is eminently suitable. In the meantime electrical winding is done in cases where there is a central electric station of sufficient power, and a winding-plant has been constructed with an electric motor of 600 h.p., but this at present is an unusual size.

The mine manager must always bear in mind that his electrical transmission must be justified by one of two reasons, if not by both. One is economy of steam power, the other is convenience or safety. For underground work, convenience is often of itself a sufficient reason; for surface work convenience is not often a sufficient reason for adopting electrical transmission on a large scale. It is therefore necessary that economy should be proved. For this purpose, a trial estimate must be made of the capital outlay in each case, and then of the working costs. The following is an approximate estimate[1] of the cost of a high-class electric generating station of 2,000 h.p. Steam pressure in boilers, 180 lbs.; boilers provided with super-heaters; three compound condensing-engines, each of 1,000 I.H.P., providing for one engine to be stationary, ready for use in case of accident to either of the other two; on each engine is a three-phase generator delivering current at 550 volts. The engine-house contains a switchboard where the various electrical currents are collected and distributed.

	£
Boilers and fittings, super-heaters, steam-pipes, dampers, and feed-pumps erected complete, say, ten boilers, eight to be at work at one time, at £900	9,000
Boiler-seating, flues, chimney, roof, and drains, at £350 a boiler	3,500
Three steam-engines, each of 1,000 I.H.P., with condensers, air-pumps, circulating pumps, and all necessary pipes and lubricating arrangements erected complete in full working order, at £4 10*s.* per h.p.	13,500
Three generators, each of 900 E.H.P., erected complete at £2 10*s.* per E.H.P.	6,750
Electric conductors, switches, switchboard, and all electrical appliances required for generating station	2,000
Engine-house, engine foundations, and all buildings required .	3,000
Cooling pond	2,000
	£39,750

Or, in round figures, £20 per I.H.P. actually at work.

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[1] The cost of land is not included.

This electric plant is to supersede a steam-distribution plant, and we will assume for the sake of argument that the cost of the steam pipes and steam motors will be about equal to the cost of the electric-distribution conductors and the electric motors. Assuming that the economy of steam by means of the electric distribution is 50 per cent., we shall require for the steam-distribution plant the following outlay for boilers :—

	£
Twenty boilers at £900	18,000
Seating, chimney, and roofing for 20 boilers, at £350 .	7,000
Total	£25,000

Deducting this from the outlay on the electric plant, we have an additional outlay for the latter of £14,750.

Working Costs.—1. *Electric Plant.*—Assuming a consumption of steam of 20 lbs. per I.H.P. on an average of 1,500 h.p. for 10 hours a day, and of 800 h.p. for 14 hours a day, or a total steam consumption per diem of 524,000 lbs.; assuming also that 3 lbs. of fuel will produce 20 lbs. of steam, we have a daily fuel consumption of 35 tons. At a colliery this fuel may be valued at about 4*s.* per ton on an average; at any other mine the price will be increased by the cost of conveyance from the colliery. We have, therefore :—

	£	*s.*	*d.*
Fuel, 35 tons at 4*s.*	7	0	0
Stokers' wages, about 1*s.* per ton of fuel . . .	1	15	0
Engine-men, cleaners, and electrician, 40*s.* a day .	2	0	0
Oil and sundries, say	1	0	0
Total	£11	15	0

The cost for the above work of 26,200 I.H.P. hours would be about $\frac{1}{9}$*d.* per I.H.P. hour. The repairs and renewals to maintain the plant in perpetuity should not exceed 10 per cent. on the whole cost, or, say, £3,975 a year = $\frac{1}{8}$*d.* per I.H.P. hour (allowing 300 days in the year), or a total cost of ·230*d.* per I.H.P. hour.

2. *Boiler Plant.*—The boiler plant will use twice as much fuel, or, say,

	£	*s.*	*d.*
Fuel, 70 tons at 4*s.*	14	0	0
Stokers' wages, about 1*s.* per ton of fuel . . .	3	10	0
Foremen	0	10	0
Total	£18	0	0

—showing a difference in favour of the electric plant of £6 5*s.*

Taking 300 days in the year, and an economy of £6 5*s.* a day, we have a total saving of £1,875 per annum, which is about 12½ per cent. upon the extra cost of the electric plant. The above is not given as an estimate which represents actual facts, because these will vary from day to day with the market price of machinery, and with many other circumstances applicable to each case; thus the electric plant might be erected for a great deal less than the figure above given, and so also might boilers for the steam plant. Also the economy of fuel expected as a result of putting up the electric plant might be much more than 50 per cent. of the fuel which the steam plant would consume, and, on the other hand, it is conceivable that a steam plant might be erected and managed with such skill as to reduce considerably the possible economy to be gained by the substitution of electrical transmission. If instead of a plant of 2,000 I.H.P. we take any smaller or larger figure for the purposes of comparison, it will only be necessary to divide or multiply the above estimates, as the case may be.

If, as is probable, the steam-transmission plant consumed three times the steam used by the high-class electric plant above indicated, then the capital outlay for the steam plant would be £37,500, the working cost per diem would be £27, and the daily economy by the use of electricity would be £27—£11 15*s*.=£15 5*s*., or for 300 days a total of £4,575.

Description of Electrical Current.—When erecting a central electric power station, after deciding on the purpose and size of the installation, one of the first questions that arise for determination is the kind of electricity, whether continuous-current or alternating-current, the latter being divided into single-phase, two-phase, and three-phase; the next question is the voltage, or electro-motive force; and the third question, if alternating current is adopted, is the periodicity, or the number of periods per second.

Continuous Current.—Hitherto most installations erected for the purpose of generating electric current for transmission of power in England have used continuous current. It is also largely used in every country; in fact, it is only since 1890 that alternating-current motors have come into favour. Previous to that date alternating currents were chiefly used for lighting installations, particularly for long-distance transmissions, partly owing to the facility for reducing or raising pressures by static transformers. Up to the year 1890 the makers and users of electric power were trained almost exclusively in the manufacture and use of continuous-current machines; but at the present time the number of makers of alternating-current motors is so large that the user is free to adopt that system if he prefers it to continuous current. The advocates of continuous current claim for it certain advantages; amongst others is the facility with which two (or more) motors can be worked in series if required. This is one of the reasons why continuous-current motors are almost exclusively used on tramway cars. These cars are fitted with two motors, each about

25 h.p. When starting a low speed is desirable, and this is produced by putting the motors in series, which has the effect of reducing the voltage to one-half. A resistance is also put in at the start; this still further reduces the voltage and the speed. As the speed increases the resistance is taken out, until the car has reached half speed. The motors are then placed in parallel, the resistance being put in again until the car has nearly reached full speed, when the resistance is taken out. The speed of a continuous-current motor is proportional to the voltage, and if two motors are placed in series on any given circuit, the voltage on each motor is reduced to one-half. A reduction in speed is obtained by placing a resistance in the circuit, which reduces the effective voltage on the motor, but this resistance simply absorbs power and wastes it. Sometimes the voltage is reduced by passing the current through lamps; but as a rule this method of reducing the speed is only applicable to small motors, as the number of lamps required in any one place underground only absorbs a small amount of current. It is possible, but hardly ever practicable, to place three or more motors in series, and so still further reduce the speed. Another advantage of the continuous-current system is that the current from a number of dynamos may be taken into one distributing main without any difficulty arising from variations in the size and description of the dynamos or engines driving them, the only requisite being that each dynamo shall produce a voltage equal to that of the others, whereas in an alternating-current installation the various dynamos connected with one distributing main must not only produce current at the same voltage, but must each have the same periodicity as the others. A third advantage is that only two conductors are required—one for the outward and the other for the return current, whereas with a three-phase installation three conductors are necessary; though it poes not follow that the three conductors will necessarily be more expensive than the two. A fourth advantage claimed for continuous current is that arc lamps will give a better light with this current than with an alternating current.

The chief objection to continuous-current motors is found at the commutator, because here there is generally some sparking at the brushes. This may be very little, but a little spark would be enough to cause an explosion in the presence of an explosive mixture of gas and air. Various devices are used to remove the danger (see page 61). On the Continent, three-phase alternating current is often preferred to the continuous current in coal-mines, on account of the danger supposed to lie in the commutator.

Alternating Current.—The ordinary alternating current, which is single-phase, is not so suitable for general application to motors as two-phase or three-phase, owing to the difficulty of starting a single-phase motor under load. The two-phase current is considered good for motors, and is adopted at some important central stations, where both lighting and power are required. For the purposes of lighting, the current may be taken from the conductors attached to one phase, and then when it is desired to drive a motor the current can be taken from the conductors attached to the two phases (see page 98). The convenience of this system has caused the electrical engineers of the Leeds Corporation, and also of the Sheffield Corporation, to adopt the two-phase system.

The three-phase system has, however, the greatest number of advocates. It is considered that the torque is more uniform. In comparing three-phase with two-phase or single-phase, it is generally considered that the weight of copper in the cables in three-phase is only about three-fourths of that in either of the other two alternating-current systems, and that this advantage applies to most mining installations. It is sometimes claimed for the three-phase system that less copper is required in the conductors than in the continuous-current system. If equal virtual voltages are taken and a power factor of 85 per cent. for the three-phase, then there is a saving by three-phase of nearly 12 per cent. If, however, equal maximum voltages are taken (equalising risk of breakdown of insulation between the conductors), the three-phase current requires 23 per cent. more copper than continuous current. The chief advantage claimed for three-phase in mining work is the absence of commutators, and consequently of sparking at the motors. Another advantage over continuous current which three-phase transmission shares with two-phase and single-phase is the facility which it offers for high-tension transmission. The majority of manufacturers of electrical machines find it easier to make alternating-current generators of 1,000 volts and upwards than to make generators of equal voltage on the continuous-current system, although there are makers of continuous-current machines who will guarantee their dynamos up to 3,000 volts. These latter, however, are the exception, and most makers prefer alternating-current for any dynamos or motors over 600 volts. High-tension currents —that is to say, currents exceeding 600 volts—are inconvenient for use with small motors, and are seldom taken into a mine, and still lower voltages are preferred. But when the electric current has to be taken a long distance—say, exceeding three miles—a high tension is necessary in order to keep down the cost of conductors. If the transmission is on the surface, and bare conductors can be carried on poles, the economy resulting from the high voltage is, roughly speaking, inversely proportional to the voltage, because, with 10,000 volts, the current (ampères) is only one-twentieth part of that required with only 500 volts, and the weight of copper with 10,000 volts is much less than one-twentieth of the weight in the 500-volt circuit. In fact, if the transmission is for a long distance, with the same percentage loss of power, the size of copper would only be one four-hundredth of that required for 500 volts. For short distances, however, as will be seen later, this additional reduction is not possible on account of the high current density involved and consequent heating of the conductor. With a high tension more expensive insulators are required, and in other directions there will be increased expense.

The high tension, however, cannot be used in the motor or lamp before it has been transformed to a lower tension. This can be readily done with a static transformer, and this is another of the advantages of the alternating current over the continuous current, because for the reduction of voltage in a continuous current a rotary transformer is necessary, which is much more expensive than a static transformer. The loss of power in a static transformer is not large, varying from 3 to 8 per cent. But taking into account this loss, and the cost of the transformer, it is not advisable to introduce high-tension currents into a mining installation unless the distances are very great.

Voltage.—The voltages in common use are between, say, 50 as a minimum and 40,000 as a maximum. The 50 volts is suitable for the arc light, incandescent light, and for small motors. For an installation where the distance from the generator to the furthest lamp or motor did not exceed 300 yards, a tension of between 50 and 60 volts would be very suitable, unless a large power had to be transmitted. For motors of ½ h.p. up to, say, 5 h.p., it would be very suitable. It can be applied to larger motors. The advantage of the low tension for lighting is that, as arc lamps should not be supplied with current at more than 50 volts, if the voltage is higher they have to be placed in series, but if only 50 volts is in the mains then the arc lamps can be placed in parallel, and switched on or off independently one of the other. The 50-volt pressure is, of course, suitable for incandescent lamps, which are made to suit any voltage not exceeding 250, but a low voltage is advantageous for incandescent lamps, because the lower the voltage, the thicker and shorter is the carbon filament.

As the distance from the generating station to the furthest motor or lamp increases, so must the voltage at the generating station be increased; thus, at a mine where it is expected that a considerable power (say, 40 E.H.P. and upwards) will have to be delivered for a total distance from generator to motor of, say, one mile, it would not be advisable to adopt a lower voltage than 400. If the distance were likely to be two miles, it would be desirable to increase the voltage to 600. If the distance is greater than two miles, the question becomes less simple. Assuming that 600 volts at the motor is the highest voltage that can be conveniently used in or about a mine, then if a higher voltage is used there must be a transformer in the vicinity of the motor to reduce the current to a convenient voltage. The cost of the transformer would be equal to a considerable cost of mains, so that, sooner than adopt a high tension and transformers, it might be found advisable to spend money on enlarging, or adding to, the mains. For instance, a high-tension concentric cable, insulated with vulcanised indiarubber, consisting of an internal cable of thirty-seven copper wires, each 15 S.W.G. (=·1489 square inch) insulated, and surrounded with a return cable, also of thirty-seven wires 15 S.W.G., and insulated, taped, braided, and armoured, would cost, say, £800 a mile. A similar cable, of which the internal copper conductor had thirty-seven wires No. 20 gauge, having an area one-fourth that of the large cable, would cost about £400, allowing for a higher voltage being used and therefore a higher quality of insulation, or half that of the large cable, therefore the extra cost for making the cable four times as large would be, say, £400 a mile, and if the distance was three miles the total extra cost would be £1,200. Assuming that a current of 500 ampères per square inch of sectional area might be sent through this cable (37/15), the current that might be passed would be about 74 ampères, as its area is rather over $\frac{1}{7}$ square inch. This current (say, 74·6 ampères) multiplied by 100 volts would give 10 E.H.P., and by 400 volts would give 40 E.H.P. A static transformer, to transform an alternating current from, say, 1,600 volts to 400 volts, and suitable for 40 E.H.P., would cost about £200, including erection and chamber, showing that it would cost less money to put down a small high-tension cable and transformer than to put down a large cable to carry a low-tension current all the way. But it might easily happen that the question of convenience would be more important than the difference in the cost as above given. In some cases the high-tension system with transformers at every branch or motor would be convenient; in other cases a low-tension system and large cables without transformers would be better. All that can be done here is to indicate the method of calculating the cost of each system.

When we come to distances of five miles and upwards there can be no doubt that a high-tension system should be adopted.

Reasons for Economy of High Tension.—As stated in Chapter I., page 9, the electrical power of any current is the product of the volts and the ampères, and is counted in watts. One volt multiplied by 1 ampère equals a watt, and 746 watts are equal to 1 E.H.P. The size of conductor required depends on the current, which is measured in ampères, and if a conductor is of suitable size for any number of ampères—say, 74—it does not matter what the voltage is. But if the voltage at the motor end of the conductor is zero, the power or horse-power will also be zero; if the voltage is great, the horse-power is great; thus, the horse-power may be increased to any reasonable extent without increasing the size of the conductor. If the conductor is carried in the air, and therefore does not require any insulating covering, the increase of voltage adds very little to the cost of the conductor, such increase of cost as there may be being simply due to the improvements in the insulators on the posts carrying the cable, and to precautions that may be taken to prevent accidents through unauthorised people tampering with the cable. Thus, a cable of thirty-seven wires, 15 S.W.G., suitable for 74 ampères (at 500 ampères per square inch), would carry at 10 volts 1 h.p., at 100 volts 10 h.p., at 1,000 volts 100 h.p., at 10,000 volts 1,000 h.p., and at 20,000 volts 2,000 h.p. When we come to insulated cables laid in the ground at the surface, or fixed to a shaft side, or laid along the passages of a mine, the advantages of very high tension are not so great, because the higher the tension, the more expensive the insulation. It is a rule that the thickness of the insulating material must be $\frac{1}{20}$ inch for each thousand volts: thus with a voltage not exceeding 500 the thickness is $\frac{1}{20}$ inch, and for a voltage exceeding 500 it is $\frac{1}{10}$ inch up to 2,000 volts for small conductors; but for a conductor of thirty-seven wires, No. 12 S.W.G., the thickness of the insulation is $\frac{1}{7}$ inch. Outside the insulation there is a thickness of tape, braiding, and preservative compound, and then outside that may be armour, made of iron wire or iron tape. Where paper-covered cables are used, the insulated cable is drawn into a lead pipe, and an increase in the thickness of the insulating material of course increases the diameter and cost of the lead pipe.

The higher the tension, the greater the care in the management of the dynamo and the cables. This, added to the high cost of the insulation, the extra cost of appliances at the stations, and the high technical training necessary in the operators for managing very high tension currents, so reduces the advantages of high tension that some engineers, even for a transmission of ten miles, would prefer 5,000 volts or lower to any higher tension.

With regard to insulated cables in shafts and underground passages, the extra cost of insulation from that suitable for, say, 50 volts as a minimum up to 600 volts as a maximum is so inconsiderable that it may be practically disregarded, and therefore the full economy of the higher tension is obtained within these limits.

In considering the distance to which current can be carried through cable of a given size, the following rules must be borne in mind :—

I. The loss of voltage, other things being equal, and consequently of power, is exactly proportional to the length of the cable, and consequently the loss on a three-mile circuit is three times the loss on a one-mile circuit; and in calculating the loss, the length of the cables of the entire circuit from the generator to the motor, and back again to the generator, has to be calculated, except in those cases where there is an earth return. But an earth return is not usually admissible, therefore, if the distance from the generator to the motor is one mile, the length of the circuit is two miles.

II. The loss of voltage on any given length and size of cable is proportional to the current as measured in ampères—that is to say, the drop in pressure between the positive and negative mains at the generator, assuming that there is no resistance in the circuit other than that of the cable, will vary with the number of ampères, or current passing through the cable. Although the motor is only at a distance of one mile from the generator, yet the loss of effective pressure at the motor is due not only to the resistance of the mile of cable from the generator to the motor, but also the mile of return cable from the motor to the generator, because the pressure required to force the current back from the motor to the generator is equivalent in effect to the back pressure in the cylinder of a steam-engine. Thus, if we had a generator giving a current of 75 ampères (more exactly 74·6 ampères) at 600 volts, or 60 E.H.P., and the drop in pressure in, say, a mile of conductor was 5 per cent. or 30 volts, then if the motor was half a mile from the generator, the circuit therefore being one mile, the voltage at the motor would be 600—30, or 570. If the amount of current should be doubled, or 150 (149·2) ampères be sent through the same mains, then the loss of voltage will also be doubled, and will be 60 volts, and the effective pressure at the motor will be 540 volts.

III. The loss of power on any given circuit is proportional to the square of the current—that is to say, with a current of 200 ampères there will be four times as much power lost as with a current of 100 ampères, because for the double current there is double the fall of voltage.

In discussing the size of a cable for transmitting electricity, the first consideration is how many ampères can be carried without heating the conductor so as to injure the insulating material with which it is covered. The second consideration is how much of the power is to be lost or wasted in overcoming the resistance of the cable. This second consideration is purely commercial: the larger the cable, the more it costs; the smaller the cable, the more power is wasted; and the more power that is wasted, the larger must be the engine and dynamo at the generating station to produce the required power at the motor. In order to see how the matter works out, we will take a concrete example, say, 100 E.H.P. (*e.g.*, 186½ ampères at 400 volts) delivered to a motor two miles distant from the generator, the motor working 10 hours a day for 300 days. Multiplying 100 × 10 × 300, we have 300,000 h.p. hours a year. If we value the horse-power delivered at 1*d.* per hour, we have 300,000*d.* = £1,250. If we allow a loss of voltage of 10 per cent. of that at the motor in the circuit, we shall require a cable with a sectional area in copper of ·82 square inch; a cable 91/12 has an area of ·76 square inch. The current density in this cable will be 245 ampères per square inch. We will value the cost of this single-conductor cable at £990 per mile, or, say, £3,960 for the circuit, and the cost of fixing it, including the cost of putting it down the shaft and along the mine, at £400, making a total of £4,360. The power of the generator, being 10 per cent. in excess of that of the motor, is 110 E.H.P., and the I.H.P. of the engine being, say, 25 per cent. more than the E.H.P., is 137½. Taking the basis of cost given on page 137 for generator, engine, boilers, condensers, &c., at £20 per I.H.P., we have the cost of the generating station, 137½ × 20, or £2,750. If instead of a loss of 10 per cent. we had a loss of 20 per cent. in the cable, the cost of the cable would be reduced, because it would be one-half the size, and its price would be £620 a mile, or £2,480 for the four-mile circuit. The cost of erection would be practically the same, say, £400, making a total of £2,880; but the power at the generating station would be increased to, say, 120 E.H.P. + 25 per cent., making a total power of 150, which, at £20 per I.H.P., brings the cost of the generating station up to £3,000. In the first instance the drop in voltage was 10 per cent., and the loss in working is one-tenth of the power actually used at the motor. One-tenth of £1,250 is £125. Where the 20 per cent. loss was sustained the loss is one-fifth of the utilised power. One-fifth of £1,250 is £250. The saving by having only a 10 per cent. drop is £125 a year. If instead of reducing the conductor we had doubled the size, we should have a total cost for the cable of £8,320 (see Table I., Column C), instead of £4,360 as in the first instance; the loss in transmission would be only 5 per cent. of the power at the motor; the E.H.P. at the generator would be 105; the I.H.P. would be 131; and the cost of the generating station £2,620. The loss would be one-twentieth of £1,250, or £62 10*s.* a year.

The above calculations, and some others, showing different voltages, percentages of loss in transmission, and distances, are given in Table I.

It will be seen in this table that the amount of drop in voltage, or loss of power in transmission, has to be regulated, in the shorter-distance transmissions, not by the simple question of cost of cable, but by the question of heating, so that in the shorter transmissions the cable is made larger than would have been necessary if the question of cost of transmission only had been considered. The size of cables of which the cost is given in the table is also slightly modified in order to use standard sizes of cables, and the prices given are averaged from makers' lists, and do not necessarily represent the actual cost of cables, which might to some extent be modified by special quotations.

In Table I., in Columns A, B, and C, transmissions of half a mile, one mile, and two miles, with a voltage of 400 at the motor, are compared, and with losses of 5 per cent., 10 per cent., and 20 per cent. for the total distance in each case, except where modified by considerations of temperature. We have also, in Columns D, E, F, and G, transmissions of half a mile, one mile, two miles, and three miles, with a voltage at the motor of 600, and a total loss in each case of 5 per cent., 10 per cent., and 20 per cent., except as modified by temperature considerations. The cost of the generating station and cables (including erection) is given in each case;

TABLE I.

	D	
Miles from to Motor	600 Volts, ½ M e fr Generator to Mot	
·5		124·4
4		680
q. in. s 91/12= . each		— ·183 sq. in. 37/14=·183 sq. i
2 cent.		680 5 per cent.
£7,920 200 200 P. } 2,620 £10,940 7,110 £3,830	{105 E.H.P. 131 I.H.P.}	£334 200 50 2,620 £3,204 3,196 1 £ 7 1
£1,250 68 £1,318	(5 I.H.P.)	£1,250 62 1 £1,312 1
7		1,360
in. ·76 sq. in. 5 cent.		800 ·156 sq. in. No. 19/12=·159 sq. 784 5·75 per cent.
£3,960 200 200 P. } 2,750 £7,110 6,000 £1,110	{106 E.H.P. 132½ I.H.P.}	£196 1 200 50 2,750 £3,196 1 — —
£1,250 135 £1,385 1,318 £ 67	(5 h.p.)	£1,250 72 £1,322 1,312 £ 10
		2,720
in. ·40 sq. in. cent.		800 — — — 5·75 per cent.
£2,480 200 200 3,120 £6,000 £1,250 255 £1,505 1,385 £ 120	As above	
nt.		5 per cent.

es are taken from makers' lists.

but the motors and all electrical appliances, &c., at the motor station are not included. The value of the power lost is taken at 1*d.* per E.H.P. per hour, which no doubt in many cases exceeds the cost of production. Referring to Column B, with 400 volts at the motor, and a transmission of one mile from generator to motor, we can compare the figures where there is a loss of 10 per cent. and 20 per cent., and we find in the latter case an increased annual cost of £85, and a diminished first cost of £278; £85 is 30·6 per cent. on the extra cost of the 10 per cent. installation, so that the additional cost of it would be repaid in a little over three years with interest, or, looking at it from another point of view, the extra loss in the 20 per cent. installation is equal to 2 per cent. interest on the whole cost of the generating station and cables.

Comparing 10 per cent. with 5 per cent. loss, we have a saving in the latter case of £59 a year working cost; but the extra capital outlay is £610, and the saving of £59 a year is under 10 per cent. on the increased outlay. It is evident, therefore, that the 5 per cent. installation is not worth the extra expense.

Heating of Cable.—The loss in transmitting the current of electricity is represented by heat generated in the wire. In an insulated wire the insulation is liable to damage by heat, and in any case the resistance is largely increased if a high temperature is reached, and therefore it is essential for safety and economy that no excessive current should be continued for many minutes. A calculation of the heat generated in the conductor will show the amount of power wasted. This may be represented by the following formula in horse-power :—

$$\text{h.p.} = \frac{C^2R}{746} = C^2 \times R \times {\cdot}00134.$$

In the above C represents the current in ampères, and R represents the resistance in ohms. For the sake of example, let us suppose a copper conductor, exactly 1 square inch in area and 1,000 feet in length. Then R, the resistance in ohms, will equal ·00833. Let us now suppose a current of 1,000 ampères. Then, $\frac{C^2}{746} = \frac{1{,}000 \times 1{,}000}{746} = 1{,}340{\cdot}5$. Multiplying this figure by ·00833 we get 11·166, or a loss in round figures of 11 h.p. This represents, perhaps, a very small percentage of the power passing through the main. One thousand ampères at a voltage of 746 equals 1,000 h.p., and 11·2 is a little over 1 per cent. If, however, the cable, instead of being only 1,000 feet in length, were a mile in length, the resistance would be increased as 1,000 : 5,280; that is to say, the loss would be increased more than fivefold. In round figures, the loss would be about 60 h.p., or 6 per cent.; and if the complete circuit were two miles long the loss would be 120 h.p., or 12 per cent. If the conductor, instead of being exactly 1 square inch, had been half the area—that is to say, ½ square inch—the resistance would have been exactly double, and the loss would be exactly double; therefore, instead of being 12 per cent. as above, it would be 24 per cent. of the power generated, or nearly one-third of the power delivered. But a current density of 1,000 ampères per square inch is as large as it is considered wise to take, and it is often thought advisable to take a less current density. In the instance given (Table I.), where there is a two-mile circuit (the motor being one mile from the generator) with a drop of 10 per cent., the number of ampères in the cable is 186½, the cross-section of the cable is ·41 square inch, and the density of the current is 455 ampères per square inch. In the preceding examples of 5 per cent., 10 per cent., and 20 per cent. loss, the size of the conductor is calculated after the following manner: —

The motor is assumed to be one mile from the generator; the E.H.P. delivered to the motor is 100; the voltage at the motor is 400, and the drop on the cable is 40, making the voltage at the generator 440. The work done at the motor, if taken in watts, is 100 × 746, or 74,600 watts. Dividing the watts by the volts—that is to say, dividing 74,600 by 400, we have the ampères—186½. The drop, being taken as 10 per cent. of the voltage at the motor, is also 10 per cent. of the power at the motor, or one-tenth of 74,600 watts—*i.e.*, 7,460 watts—and the loss of power in watts due to the drop on the line is shown by the formula—

$$\text{Loss in watts} = R \times C^2 \text{ (in ampères)}.$$

In this case, $7{,}460 = R \times 186\tfrac{1}{2}^2$, or,

$$R = \frac{7{,}460}{(186\frac{1}{2})^2} = \frac{7{,}460}{34{,}782} = \cdot 214.$$

$$\begin{aligned} R &= \cdot 214 \text{ ohm.} \\ &= \cdot 107 \text{ ohm per mile.} \\ &= \frac{\cdot 107 \times 1{,}000}{5{,}280} \text{ ohms per 1,000 feet.} \\ R &= \cdot 0202 \text{ ohm per 1,000 feet.} \end{aligned}$$

It was stated above that the resistance of a square inch of copper 1,000 feet in length was ·00833. If we do the following sum in proportion we shall get the required sectional area of the conductor. As:

$$\cdot 0202 : \cdot 00833 :: 1 : x. \quad x = \cdot 412.$$

In the above manner the sectional area of any conductor can be calculated. An easier way of doing this is to remember that with a current density of 800 ampères per square inch the drop in voltage in a copper conductor is 2 volts per 100 yards, and that the current density is proportional to the drop of voltage, and inversely proportional to the length of cable. Thus, with a drop of 40 volts in two miles, the current density equals $800 \times \frac{100}{2 \times 1{,}760} \times \frac{40}{2} = 454{\cdot}5$ ampères per square inch; therefore, the area of cable required to carry 186·5 ampères $= \frac{186{\cdot}5}{454{\cdot}5} = {\cdot}41$ square inch.

Referring to the examples given on pages 145 and 146, of a motor or motors of 100 E.H.P. two miles distant from the generator, and the comparative cost, the results, as seen in the table, are very different if the distance of the motor from the generator, instead of being two miles, is reduced to half a mile, and with the same percentage of loss in each case the size of the conductors is also a quarter. In dealing with insulated cables the cost is not always exactly proportional to the size of the conductor, and the cost of fixing in the shaft will be about the same in each case. We need not consider here the case of 20 per cent. loss, since the current density in this case comes out to 1,820 ampères, which is much too high. The current density with a 10 per cent. loss—namely, 910 ampères—is also too high, so that instead of 10 per cent. we must take a loss of 8·5 per cent., which gives a current density of 770 ampères. Then the relative cost of cables and erection for 8·5 per cent. and 5 per cent. loss will be £696 and £870, and, adding the cost of the generating station, the total costs are respectively £3,396 and £3,490. Here it appears that the 5 per cent. installation gives the best arrangement; that is to say, that a drop of 5 per cent. is the most economical, since the saving in working cost of £42 per annum is effected by an increased capital expenditure of only £94, giving a rate of interest of 45 per cent. The conditions would be again altered if, instead of reducing the distance to half a mile, we made the distance from the generator to the motor one mile, as in the case shown in Column B of the table. By the assumption the loss of power in the cable is the same whether the motor is half a mile, one mile, or two miles from the generator; but in these last instances, where the motor is two miles from the generator, it is probable that the installation, where the loss of power is 20 per cent. of the power utilised at the motor, is the most economical arrangement. To reduce the loss from 20 per cent. to 10 per cent. requires an expenditure of £1,110, and the resulting economy is £120 a year, giving a return of 10·8 per cent. on the additional outlay. Without making further calculations of this kind, we can see at once that if we increase the length of the circuit we must submit to a greater drop in the voltage and consequent loss of power.

Effect of Increasing the Voltage.—In the above instances the somewhat low voltage of 400 at the motor has been taken. If we increase the voltage to 600, we shall again find a striking difference in the capital outlay. The effect of increasing the voltage in the proportion of 400 to 600, if the same percentage of power loss is maintained, will be to decrease the necessary sectional area of the cables in similar ratio twice over, because the voltage drop is greater, being 60 instead of 40, the current is less, being 124 ampères instead of 186; the loss varies as current squared, and the cable resistance increases as its size diminishes. Thus, for equal percentage power losses the size of cable varies inversely as voltage squared, or as $600^2 : 400^2$—that is, as $3^2 : 2^2$, or as 9 : 4. And since it will not materially affect the thickness of the insulation of the cables (in fact, the same quality of cable will be used), the cost will be reduced in approximately the same ratio—that is, as 9 : 4.[1]

Referring to Table I., 600 volts, one-mile transmission, with a 10 per cent. drop of voltage and a 10 per cent. loss of power, Column E, we find the cost of the cable erected is £968, the cost of the generating station £2,750, and the total cost £3,718. With an 11·5 per cent. loss (the maximum allowable), the cost of the cable erected would be £693; generating station, £2,784; total, £3,477; and with a 5 per cent. loss the cost of the cable would be £1,540; generating station, £2,620; total, £4,160. From the table it appears that in this case the most economical drop is from 5 per cent. to 10 per cent. From Column D it appears that a loss of 5 per cent. is the maximum permissible in a half-mile 600-volt transmission, for no greater drop can be taken without undue heating. When we come to the two-mile transmission (see Column F), it is evident that a total drop of 10 per cent. is the most economical arrangement.

In all the above instances the cost of the cable is calculated as going down a shaft about 500 yards deep; but if the installation had been entirely on the surface, where a bare copper conductor could be carried on poles, the cost of the cables would be much less.

With the above transmission of two miles from generator to motor, it is evident that we approach the verge of the distance to which we can profitably go with low-tension currents, but, in order to make sure, we have worked out the results with a distance of three miles and a tension of 600 volts (see Column G). As compared with the two-mile transmission, the length of the cable has to be multiplied by one and a half, and the area has also to be multiplied by one and a half, because it is necessary to increase the sectional area of the conductor in order to maintain the given drop of 10 per cent. (really 9·15 per cent.). Thus, the cost of the cables for the three-mile transmission is £7,520; add the cost of the generating station, £2,730, and we have a total cost of £10,250. With a drop of 20 per cent. (really 18·1 per cent.), we have the cost of mains £3,314; add the cost of the generating station, £2,940, and we have a total cost of £6,254. It is at once evident that 20 per cent. is the least drop that we can employ in this case, and the next question is, Would it be profitable to have a greater drop, say, 30 per cent.? The effect of that would be to reduce the area of the cable in the proportion of 3 to 2. This gives the area of the cables ·183 square inch. A No. 37/14 cable has this area and costs £334 per mile; making a total cost of cable, including erection, of £2,504. The cost of the generator will be ascertained as follows:—

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[1] It will be seen from the table that the cost works out at a ratio of about 9 : 5; in most cases the cost of manufacture of the smaller cable is a little greater than that of the larger in proportion to its size.

100 E.H.P. + 30 per cent. for loss in transmission = 130 E.H.P + 25 per cent. = say, 162 I.H.P., and this at £20 per I.H.P. = £3,240. Adding this to the cost of the cable, we have a total cost of £5,744. The loss in working is 30 per cent. of £1,250—that is to say, £375 a year. As compared with a 10 per cent. drop, the reduction in capital cost is £4,506, and the loss in working is £261 a year more, or about 6 per cent. Comparing it with a 20 per cent. drop, the latter has an extra capital cost of £510, and an economy in working cost of £149 a year. Therefore, it appears that for a three-mile transmission (from generator to motor), with 600 volts at the motor, we must have something like a 20 per cent. drop.

Averaging the Distance to which the Power is taken.—In distributing power at a works similar to a mine it is generally the case that the power is required at a great variety of places, some much nearer than others to the generator. We might put down low-tension generators and cables for driving those motors which are near to the station, and high-tension generators and cables for those which are distant; but this at once leads to complications in working and to additional expense at the generator station and in the cables, due to complications. It is necessary to have spare generators at the station, so that the works may not be stopped by the breakdown of one machine, and for every class of machine we have we must also have spare machines. For this reason it is generally advisable to sacrifice some economy in transmission for the sake of avoiding the complication of having a variety of generators which cannot be substituted one for the other, and a variety of cables which cannot be tapped for any machine about the works as required. Therefore, in calculating the required voltage for a works, we have to consider the average distance to which the power has to be taken. Thus, out of 2,000 I.H.P. at a mine, there might be the distribution of E.H.P. shown in the table on page 152.

The total of 1,610 E.H.P. will absorb the 2,000 I.H.P. of the generating station. It will be seen that 830 E.H.P., or more than one-half, does not exceed half a mile; 270 E.H.P. exceeds half a mile and does not exceed one mile; 350 E.H.P. is two miles, and 160 E.H.P. is at three miles. Looking at the column of E.H.P. miles, we find that the average distance of transmission is $\frac{1711}{1610}$, or a little over one mile.

We can, therefore, treat this as a one-mile transmission, and on a basis similar to that given in Table I., Column B, for a transmission of 100 E.H.P. It is, therefore, possible to deal with this economically with 400 volts at the motor and a 10 per cent. drop in voltage—*i.e.*, 440 volts at the generator.

TABLE SHOWING POSSIBLE DISTRIBUTION OF POWER AT A MINE.

Description of Engine	E.H.P.	Average Distance from Generator in Miles	E.H.P. × Miles
Pumping	200	⅓	66
Ventilating fan	200	¼	50
Screens and washing-machines . .	150	¼	38
Workshops and saw-mill . . .	80	⅙	14
Sundry inclines and other work . .	50	½	25
Lighting works on surface . . .	50	½	25
Lighting village	100	1	100
Pumping-engine in pit	30	¾	23
,, ,, ...	40	1	40
,, ,, ...	50	2	100
,, ,, ...	60	3	180
Hauling engines	100	½	50
,, ...	100	1	100
,, ...	100	2	200
,, ...	100	3	300
Auxiliary fans	200	2	400
Total . . .	1,610	—	1,711

If the voltage was raised to 600 at the motor, it would be more economical still, but this is unusually high for a colliery installation, and it would be better to fix the voltage at the generator at 500 or 600. If a voltage of 550 at the generator is adopted, and a drop of 50 volts per mile of distance between generator and motor, then the voltage at the motor will average a little under 500, but at all the motors over one mile it will be less than 500; for instance, at those two miles off it will be about 450, and at those three miles off it will only be 400, and the speed of the motors will be proportionately reduced, unless they are specially designed for these voltages. If we assume that at this particular mine some portion of the power—say, not exceeding 200 E.H.P.—had to be taken even further than three miles from the generator—say, four miles—it would still be within reach of the generating station, because although the loss of 200 volts, or 57 per cent. of the utilised power, would be heavy, it would only be on one-eighth part of the total supply.

The above case illustrates a very common problem when it is desired to supply a great variety of machines with power, both near and far; but there are other cases, where the electrical power is required, not for the supply of any machines near to the generator, but entirely for those at a distance, and it is at once evident that the question of a higher voltage must be seriously entertained, in order to keep down the capital cost and the loss in working. In the last-mentioned example, where a total of 1,610 E.H.P. is transmitted at a drop of 50 volts, or 10 per cent. per mile, an average distance of $1\frac{1}{16}$ mile, the cost of the cables, erected ready for work, would probably be some figure between £12,000 and £20,000, varying with the price of copper and the nature of the insulation employed, the number of separate cables, the conditions of the shafts, &c. If the current is carried in cables averaging, say, eight large armoured cables, and down a shaft 500 yards deep, the cost will vary from, say, £12,000 to £17,000, including fixing. But if, as is more probable, there is an average of, say, sixteen armoured cables, the cost will vary from, say, £15,000 to £19,000. This represents an outlay of capital upon which it is worth while to attempt to make a saving by increasing the voltage, and in other ways, if it can be done without a corresponding increase in other parts of the system and loss in efficiency.

Reduction of Cost by Increasing Size of Cable.—It is probable that in the example given there will be a number of cables, going on different roads and kept well separated from each other both in the shafts and underground, so that a defect in one cable will not necessarily lead to the stoppage of the whole work. But sixteen highly-insulated, lead-covered, and armoured cables, each carrying 100 E.H.P., will be much more expensive than four cables each carrying 400 E.H.P.; and in the case where all the current is required for a long-distance transmission, it is probable that for a great part of the distance all the current can go in large cables and at a reduction of perhaps 20 per cent. in the average cost per h.p. transmitted. In the case of the transmission two miles, with 400 volts at the motor and a drop of 10 per cent. per mile from generator to motor, the cost of the cables for 100 E.H.P. was put down in Table I., Column C, at £2,480, and erection £400. If these figures were multiplied by 16, we should get £39,680 + £6,400 =£46,080, as the cost of the cables and of erection; but if all the power were taken this distance, it might probably be taken in, say, four large cables, each of 400 h.p., and, reducing the cost of the cables by 20 per cent., the cost would be £36,800; and the question at once arises how this figure can be reduced. We have to reconcile two conflicting needs: one is the convenience and safety of low-tension motors, &c.; the other is the economy of high-tension mains.

Three-wire System.—If we use continuous, or, as it is otherwise called, direct, current, we may conveniently adopt what is called the three-wire system. By this system we can double the voltage at the power-house by putting two generators in series, and the motors we employ in the mine are used at half the voltage which is generated in the power-house, less the drop in transmission. Thus, in the case of the two-mile transmission, we might have two generators in series in the power-house, each of 480 volts. A 20 per cent. drop over the four miles of cable would give us 400 volts at the motor. The conductors or cables are laid in sets of three. The middle conductor is the neutral or balancing conductor, and the two outers are the positive and negative conductors. The motors will be arranged alternately—the first motor between the positive conductor and the neutral conductor, and the second motor between the neutral and the negative conductors. It is assumed that the motors will be worked in pairs of approximately equal power. It is not necessary that they should be very near together. They may be hundreds of yards apart, and the pair may consist, say, of one motor of 60 h.p. on the positive side and two motors, say, each of 30 h.p., on the negative side, the endeavour being to arrange the motors so that there shall be as nearly as possible equal powers on each side of the neutral conductor. If the powers are quite equal, the negative conductor will act as the return cable for the positive conductor, and the practical effect on the voltage is as if each pair of motors were run in series, the same as the generators. If the pairs are not of equal power, or do not happen to be working at equal powers, then the neutral conductor takes the balance of the current, and must be made of a size suitable for the purpose. Since the size of the cables for a given loss of power varies inversely as voltage squared, the size of the cables on the three-wire system is only one-fourth. But this saving of three-quarters is not really made, because there is the cost of the middle wire. If the power on the positive side is 4, and that on the negative side 2, then the balancing-wire will have to be equal to 2. For the purpose of comparison with the two-wire system, we may call the cost of that system 16, the cost of the outers of the three-wire system $2 + 2 = 4$. The cost of the middle wire is half one outer = 1, and the cost of the two systems will therefore be as 16 : 5. But it is possible that while the full load might be on one side, there might be no load on the other side; in this case the middle wire would have to carry a current equal to that in the outer, so that it will be better to make the three wires of equal size, especially if the number of motors is not large; in this case the cost of the middle wire will be 2 instead of 1, and the relative cost of two- and three-wire systems will be as 16 : 6, or 8 : 3. In the case of the three conductors taken into a district where there are a number of motors, it will generally be possible, by means of suitable switches, to connect the motors on to that side, positive or negative, which is best for evenly balancing the current. But if we have a middle wire of the same section as the outers, this arrangement will be unnecessary, and if one side is entirely cut off, only one generator need be run, and the system will become for the time being a simple two-wire system.

Applying this reasoning to the example above given—namely, a 400-volt two-mile 1,600 h.p. installation, and allowing the same drop—that is, 10 per cent. per mile—we have the cost of cables on the three-wire system, six-sixteenths of the previous cost =£39,680 × $\frac{3}{8}$ =£14,880. But the current density is too great, being 932 ampères per square inch, therefore the size and cost of the cable must be increased in the ratio of 932 : 800, making the cost £17,335, and, taking the cost of erection at £6,400 × $\frac{3}{4}$ =£4,800, we have the total cost £22,135. If we raise the voltage to the highest which is generally considered admissible in this kind of transmission—*i.e.*, to 600 volts at the motor-house—and take the greatest drop permissible for a density of 800 ampères as above—that is, 137 volts in the circuit, giving 1,337 volts between the outers at the generators—we can reduce the size and cost of the cables in the ratio of the voltage—that is, as 600 : 400 :: £17,335 : £11,556. Adding £4,800 for erection, total cost £16,356. The total loss in transmission is 17 per cent. with 400 volts, and 11½ per cent. with 600 volts at the motor. If it is desired to reduce the cost of the cables still further, there are two possible systems.

High Tension.—The first we will take is the continuous-current system, either three-wire or two-wire, and the voltage may be raised at the generating-house up to, say, 2,000 volts on each generator, or, on the three-wire system, to a total of 4,000 volts. But there are comparatively few makers who will undertake to make continuous-current generators of this high voltage. Most makers of this class of machinery object to exceed 600 volts, alleging that there is a great liability to failure. The high voltage is also unsuitable for the small motors generally used in mines, and it is necessary to transform it. The transformer used for the purpose is a rotary transformer. Sometimes a special machine is used, and sometimes the rotary transformer simply consists of a motor at one end of the shaft driving a generator at the other end of the shaft, the generator being so wound as to give current at the required voltage, which may be, say, 400, or any other convenient tension. This transformer, or motor-generator, will absorb from 6 per cent. to 50 per cent. of the power, according to its size, and it will cost from £5 to £6 per E.H.P.

Alternating Current: High Tension.—The other method is by alternating-current machines and static transformers. When we get to this system we at once go for high tension—that is to say, any tension not exceeding 3,000 volts. With, say, 2,000 volts we shall be able to reduce the cost of the cables very greatly. It is assumed, for the purposes of the following calculations, that the size of cables required for alternating current is not materially different from that required for direct current for approximately the same voltages. Going back to the example, Table I., Column C, of a 100 E.H.P. two-mile transmission, with 400 volts at the motor and a drop of 10 per cent. from the generator to the motor, or a total drop of 20 per cent., we have a voltage at the generator of 480. If, for the sake of convenience in calculation, we multiply 400 volts by five, we get a voltage at the alternating transformer of 2,000, and allowing a total of 20 per cent. for loss in transmission (that is, 10 per cent. per mile) in the cable, we get a voltage at the generator of 2,400. The cost of the cables at the low tension was £2,480 + £400 for erection, and multiplying these by 16, to make up 1,600 h.p., gives totals of £39,680 + £6,400, equals £46,080, cost of the cables and erection. With the increased voltage we may divide the cost of cable by $5^2 = 25$, reducing £39,680 to £1,587; but this cost must be doubled on account of extra insulation and smaller size, so that the cost of the cables (7/17) will be £3,174 + the erection of the sixteen cables at £300 each, or, say, £4,800, making total cost £7,974. But with the above drop of 400 volts, the current density will be increased five times, from 466 ampères to 2,330 ampères, and this is too much, therefore the current density should be reduced by enlarging the cable three times, using 19/17, thereby increasing the cost from £3,174 to £8,320, adding erection, £4,800, making the total cost £13,120. The total loss in transmission will be reduced from 20 per cent. to 7 per cent. To this has to be added the cost of static transformers, which at £3 per E.H.P. (including chamber and fixing), would be approximately £5,000, or a total cost of £18,120 for cables and transformers. Compare this with £16,356, the cost of cables alone on the three-wire system (page 155) with 600 volts at the motor, and no transformers, and a loss of 11½ per cent. in transmission: 11½ per cent. of 1,600 E.H.P. = 184 E.H.P. of loss, and adding 25 per cent. to turn into I.H.P., makes 230 I.H.P., which at a cost of £20 per I.H.P. costs £4,600. The loss on the alternating system is $\frac{7}{11{\cdot}5}$ of the above, or the capital outlay to meet this loss is £2,800. The annual loss at 11½ per cent. = £144 per 100 E.H.P. delivered, and for 1,600 E.H.P. delivered is £144 × 16 = £2,304. If the loss is 7 per cent. it will be £1,400, so that the annual saving by the alternating system will be £904. The extra cost of generating station for the three-wire system = £1,800. The extra cost of cables and transformers for the alternate-current system = £1,734; so that there is a balance of £276 of capital cost in favour of the alternate-current system; but the two systems on the whole are about equal in first cost and working cost in this instance.

If we go to a distance of three miles and keep the same drop of potential per mile, or a total drop of 17½ per cent., the cables on the three-wire system with 600 volts at the motor would cost just 50 per cent. more than for two miles—that is, £17,334, adding erection £6,000 = £23,334. With the cables on the alternating-current system with 2,000 volts at the transformer, and a total drop of 10½ per cent., the cost would be £12,480, and erection £6,000; total, £18,480; to which must be added £5,000 for the transformers, making a total of £23,480. This calculation shows a gain by the adoption of the 2,000-volt system of 6¾ per cent. on the first cost of generating plant, but after allowing for loss in transformers the working costs will be much the same. For a four-mile transmission and the same drop per mile, making a total of 23 per cent., the cost for the three-wire system is £17,334 × 1⅓ = £23,112, and erection £7,200; total, £30,312.

For the alternating-current system with a total drop of 14 per cent., the cables will cost £12,480 × $1\frac{1}{3}$ = £16,640, and the erection £7,200, and £5,000 for transformers = £28,840. This shows that the 2,000-volt system is £1,472 cheaper in first cost of cables, &c., and 9 per cent. cheaper in first cost of generating plant; after allowing for loss in transformation there may be some saving in working cost.

Overhead Wires.—It will very frequently happen at a mine that where there is a long-distance electric transmission the cables can be taken on the surface over private lands, and in this case there is no reason why overhead conductors and bare wires should not be used. The cost of the bare-wire conductor is very much less than that of the insulated cable, so that cables with a large sectional area of copper can be used, and the drop reduced from 10 per cent. per mile to 1 per cent. or $\frac{1}{2}$ per cent. per mile. Where this is the case, a long-distance transmission at low voltages presents much fewer difficulties than in the cases previously dealt with. An overhead cable suitable for carrying 100 E.H.P. at 660 volts at the generator a distance of two miles to the motor with a total drop of 10 per cent.—that is to say, a voltage at the motor of 600—would be 61/13, or ·4 square inch (see Table I., Column F); the copper would weigh about 8,300 lbs. a mile, therefore two miles each way would weigh 33,200 lbs.; this at 10*d.* per lb. will cost 332,000*d.*, or £1,383, as compared with the insulated cable £2,480.

To take a case of long-distance transmission—say, ten miles from generator to motor—a voltage at the generator of 5,000 and a drop of 10 per cent. for the distance, or 1 per cent. per mile—that is, 500 volts, equal to 50 volts a mile—we should have a current density of 563 ampères per square inch; the size of the cable for 1,600 E.H.P. would be $\frac{1{,}600 \times 746}{4{,}500 \times 563} \times 1$ square inch = ·47 square inch. This would weigh 9,700 lbs. per mile, or, for the twenty-mile circuit, 194,000 lbs.; this at 10*d.* per lb. costs £8,083. It would therefore be economical to use a larger conductor and a less drop. A 5 per cent. drop would save 80 E.H.P.—costing £1,000 per annum—at additional cost of £8,000, giving a return of $12\frac{1}{2}$ per cent. on the additional outlay.

Working Costs.—On page 138 an estimate is given of the working cost of an electric plant of 2,000 I.H.P., which works out to about $\frac{1}{10}$*d.* per I.H.P. per hour, or, if we add the repairs and renewals of plant, to nearly $\frac{1}{4}$*d.* per I.H.P. per hour. But in considering the amount of drop in the voltage in a long conductor, or the loss of power in a conductor, at page 145 we took the value of the E.H.P. at 1*d.* per hour. But there is, of course, a difference between the E.H.P. delivered and the I.H.P. of the engine driving the generator, the former being, say, two-thirds of the latter, and therefore our cost of ·225*d.* per I.H.P. hour as given on page 138, must be increased to ·337*d.* per E.H.P. hour at the motor. If we substitute this smaller cost for the 1*d.* taken in the above calculations, we might be led to adopt a higher drop in voltage. There is, however, a limit to the drop which is permissible, and that is caused by the heat effect of the current on the cable. The amount of drop permissible is not a percentage in every case, but such a voltage as is sufficient to force the permitted density of current against the resistance.

Heat of Conductors and Dangers.—The doctrine of the conservation of energy teaches us that whenever power is lost in one form it appears somewhere else in another form, and thus, when the E.M.F. in volts is lost in a cable, it appears in the form of heat in the wires of the cable. If a bare wire were covered with fine coal-dust—as, for instance, in the vicinity of coal screens on the surface, or on a haulage road in a pit—heating would be very likely to occur, and a small rise of temperature in the wire would warm the coal-dust and thus would increase the rate of oxidation of the latter, and so set up what is commonly called 'spontaneous combustion,' and a terrible accident might be the result. This danger is not confined to coal-dust, but is found in many other things, such as carbonaceous shales, oily rags and waste, &c.

It is, however, usual for conductors in or about a mine to be covered with insulating material, such as indiarubber or paper saturated in oily and waxy compounds, and the effect of a small rise of temperature in the conducting-wire is to injure the insulating material. A temperature of 120° F. is given by manufacturers and others as the maximum temperature to which indiarubber insulation should be exposed, but it is also believed that any rise of temperature above 60° F. is injurious and shortens the life of an indiarubber cable. It is also stated that a rise of temperature reduces the insulating power, both of the indiarubber and of the paper; so that an insulation which would be perfectly satisfactory at a temperature of 60° might be unsatisfactory at a temperature of 100°.

Cable-makers of great experience say that a current density of 1,000 ampères per square inch may be permitted without injuring the cable, in the case of cables of small size; that is to say, a cable made of nineteen wires, 16-gauge, equal to ·06 square inch, or about $\frac{1}{16}$ square inch, might be subjected to a current density of 1,000 ampères per square inch—*i.e.*, a current of 60 ampères might be sent along such a cable covered with rubber insulation. But for a larger cable the current density must be reduced to 800 ampères per square inch. The makers of cables covered with bitumen say that their cables will stand a maximum current density of 1,000 ampères per square inch up to a sectional area of ½ square inch; above that area the current density to be only 800 ampères.

It is, of course, perfectly obvious that for any given current density the larger the conductor, and consequently the larger the current and the larger the amount of heat developed by that current, the greater effect it will have in heating the surrounding insulating material; because, whilst the cooling surface increases in proportion to the diameter of the conductor, the heating current increases as the square of the diameter. If we refer to the example in Table I., showing the size of cable required to transmit 100 E.H.P. with 400 volts at the motor with a drop of 20 per cent. of voltage, or 80 volts in four miles of cable, we find that the sectional area of copper is ·41 square inch, and that the current of 186½ ampères is equal to a density of 455 ampères per square inch. It appears, therefore, that this current is well within the limits given by the makers of cables. But before we take that for granted we must consider the conditions of a cable in a mine. Generally speaking, the conditions of a mine are favourable in this respect—that the temperature is uniform. The conductor is not exposed to the hot rays of the sun or to frost. But, on the other hand, the mine, or parts of the mine, may have a permanently high temperature, and this is injurious to the insulation of the cables; and on that account the current density should be kept down so as to avoid overheating. In some few mines the temperature underground is 90° and upwards, and in many others it is over 70°. For this reason it will probably be prudent to keep down the maximum current density in a colliery to 800 ampères per square inch for small conductors, and to 600 for large conductors. This affects the question of burying conductors or of hanging them on props. In deep mines it will be an advantage to have the cables where the ventilation can keep them cool, instead of burying them in the hot earth.

When increasing the voltage for a given amount of power, we are able to use a smaller conductor, because a smaller number of ampères is required to give the same power. We are also able to use a still smaller conductor, because we can afford a higher drop of voltage. Ten per cent. of 400 volts is 40, and 10 per cent. of 600 volts is 60. In each case we lose the same percentage and the same amount of power and the same percentage of voltage; thus, with a voltage of, say, 440 at the generator, and a 10 per cent. drop and a cable ·41 square inch area, we have a loss of 10 per cent. of the power at the motor. If we increase the voltage to 660 at the generator and allow a drop of 10 per cent., we can reduce the ampères in similar ratio—that is to say, from 186 in the first instance to 124 in the second instance—and we therefore only require a cable two-thirds the original size; but by increasing the drop in voltage from 40 to 60 we are able to increase the current density per square inch in similar ratio, and therefore we can reduce the cable again. The result is that the sectional area of the cable is $\cdot 42 \times \frac{2}{3} \times \frac{2}{3} = \cdot 42 \times \frac{4}{9} = \cdot 19$, approximately. The current density is increased because we have 124 ampères in a sectional area of ·19, then as $\frac{19}{100} : \frac{124}{652}$, here we have a current density of 652, which is quite high enough.

CHAPTER IX

ELECTRICITY APPLIED TO PUMPING AND HAULING

Electric Pumping Plants, Various Types—Electric Sinking-pumps and Centrifugal Pumps—Electric Haulage: Single-rope, Main and Tail Rope, Endless-rope—Electric Locomotives.

Electric Pumping Plants.—One of the most important uses to which electricity can be put at a mine is that of pumping; and the great number of electrical pumping plants that are at present in operation gives ample proof of its reliability and adaptability for the work.

The most economical pumping arrangement for a mine, viewed from a fuel-consumption standpoint, is that in which a high-class Cornish engine, or a compound or a triple-expansion condensing engine, is fixed at the shaft top and actuates the pumps in the shaft by means of rods; such plants, however, are best suited for dealing with large volumes of water, in which case a separate shaft could be apportioned to them.

The extra losses in pumps worked by rotary electric motors arise from—

1. Conversion of mechanical power of the steam-engine into electrical power of the dynamo.
2. Transmission of electric current from dynamo to motor.
3. Conversion of electric power of motor into mechanical power on motor shaft.
4. Intermediate gearing between motor shaft and pump crank shaft.

Although the electric pump may be more costly than the steam-engine on the surface and pumps in the shaft, it has decided advantages over other forms of underground pump, such as steam, compressed-air, and wire-rope driven.

Types of Electric Pump.—The most common type of pump to which the electric motor is applied is the three-throw ram pump, in which there are three working barrels and three rams, the latter being worked by a shaft with three cranks set at angles of 120° with each other. Each ram and barrel thus constitute a separate single-acting pump (the barrels being open at the front end), with separate suction and delivery valves.

By this arrangement of three working barrels it will be seen that the work on the crank shaft of the pump is equalised, and a uniform current of water is delivered to the pipes.

Double-ram pumps are used, but are not so good as three-throw.

An important feature with regard to mining pumps is to have perfect interchangeability, and Messrs. Ernest Scott & Mountain, who have had a very long experience in electric mining work, have designed special pumps with this end in view. The pump barrels are independent and interchangeable, also the valves and connecting pipes, so that, in the event

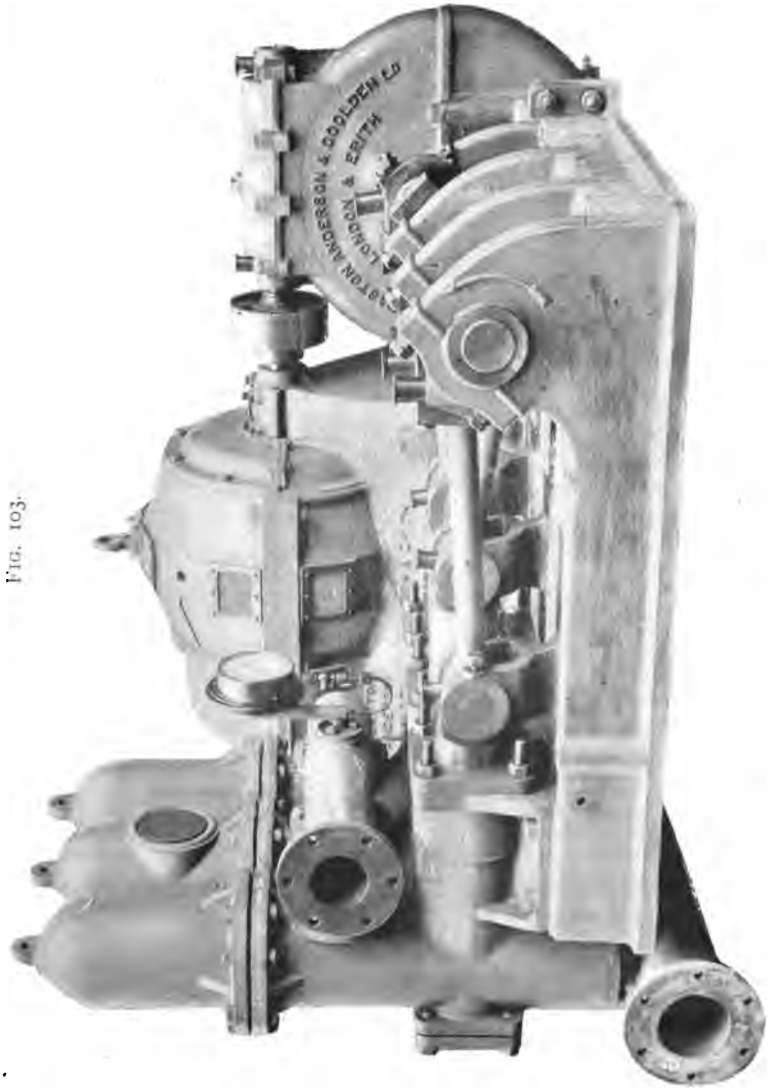


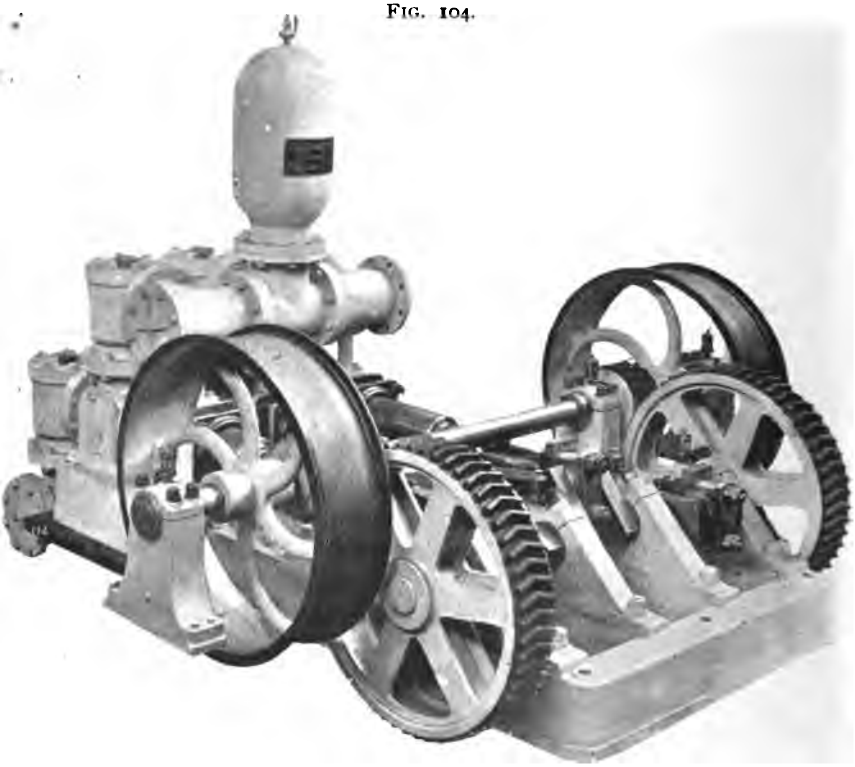
Fig. 103.

Three-throw Pump Driven by Electric Motor through Worm Gearing.

of a breakdown of any part of the pump, the remaining rams could continue working if necessary.

Speed of Pumps.—The speed at which pumps can work is limited, owing to the fact that water is incompressible and inelastic; they differ in this respect from air compressors, which rise in efficiency as the speed increases. A usual piston speed for three-throw pumps is 60 to 80 feet per minute, but it may go up to 120 feet a minute for a short period. This low speed necessitates the use of a high ratio of reduction between the motor shaft and the pump crank shaft.

FIG. 104.



LARGE THREE-THROW PUMP DRIVEN BY ELECTRIC MOTOR THROUGH A BELT AND SPUR GEARING.

This reduction in speed may be got in several ways:—

1. By means of spur-gearing only.
2. By a worm and worm-wheel (fig. 103).
3. By spur gearing and belt, or ropes (fig. 104).

The method used depends to a certain extent on the circumstances.

If the space available were limited the reduction might be obtained by No. 2 method, as this can be done with a single train of gear, the worm on the motor shaft and the worm-wheel on the crank shaft of the pump.

Worm-gearing, to be efficient, however, should be run in an oil bath; and even then the power absorbed is great, owing to the thrust of the worm-wheel on the worm, and therefore it is seldom used.

A spur-gearing only would be adopted in those situations where, owing to the atmospheric conditions, a belt or ropes could not be made to work, or where space was limited. Spur-gearing is also to be recommended for large powers, and in these cases it may be necessary to have the teeth on the wheels shrouded up to the pitch line. Helical teeth are also employed in pumps of large size (see fig. 104), and the gear wheels are duplicated. The teeth of the wheels should be machine-cut, and, for the pinions, wheels made of raw hide have been successfully used in some cases. The raw-hide pinion on the motor shaft makes but little noise, whilst the clatter of the high-speed metal pinion is deafening.

Riedler Pump.—This well-known pump, made by Messrs. Fraser & Chalmers, Erith, is specially suited for electric driving on account of the high rotative speed for which it may be designed. Over 1,500 Riedler pumps are now in operation, most of them, however, driven by steam or air, as it is only recently that they have been adapted to electric driving.

The pump is the invention of Professor A. Riedler, of Berlin, and its principal feature is a device by means of which the valves are closed mechanically rather than by the action of water due to the reversal of the plunger. At the beginning of the stroke the valve opens automatically, and remains open practically the entire stroke. When near the end, it is positively closed at the proper moment by the controller.

This controlling device permits the valve-lift to be high, thus increasing the effective area of the valve; it also permits the pump to be driven at a high piston speed. The speed of the pumps varies from 150 revolutions per minute in the smaller sizes to about 80 revolutions in the larger.

The Standard Riedler pump is of the differential type, with only one suction and one delivery valve for what is practically a double-acting pump.

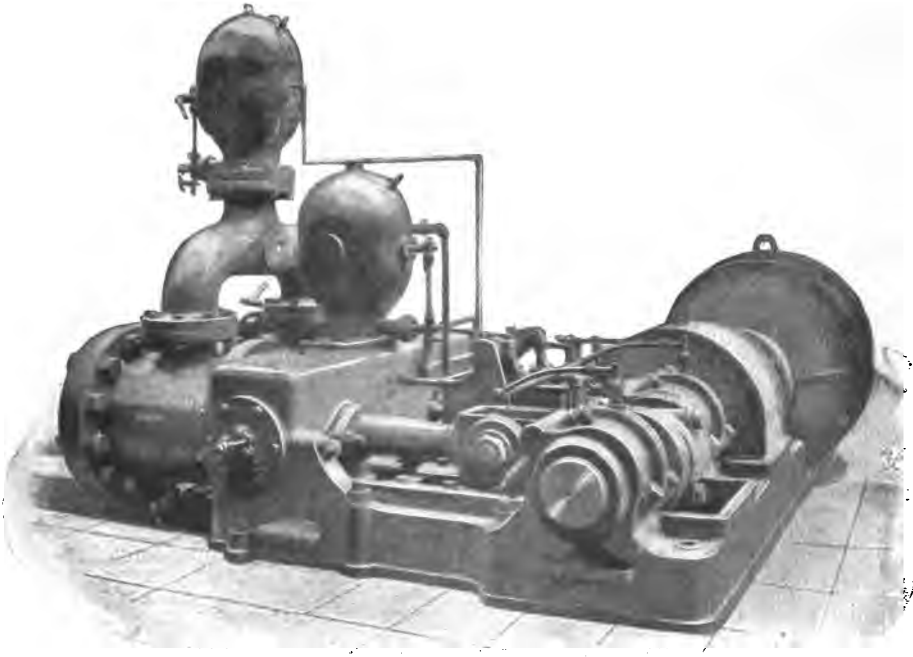
A pump capable of lifting 700 gallons of water per minute against a head of 1,500 feet would have the following dimensions: Diameter of large plunger, 9½ inches; do. of small plunger, 6¾ inches; stroke, 36 inches; revolutions, 80 per minute; B.H.P. of motor required, 361; suction pipe, 12 inches diameter; delivery pipe, 8 inches diameter.

A notable example of the Riedler pump in Great Britain is a large pump installed in 1899 for the Powell-Duffryn Collieries in South Wales. This pump has a capacity of 1,000 gallons per minute against a head of 1,600 feet, and has been running night and day for over three years.

The increased rotary speed of these pumps as compared with three-throw pumps entails of course less reduction gear, the motor being either coupled direct or else driving through a belt or gearing with only a single reduction in speed.

Riedler Express Pump.—The Riedler pumps already referred to are usually not built for heads exceeding 2,000 feet, and in the large sizes the speed of 80 revolutions per minute is somewhat low for direct coupling to the motor. This has led to the introduction of the Riedler Express pump, in which the valves are mechanically closed by a buffer attached to the plunger. The speed of these pumps varies from 250 revolutions per minute in the smaller sizes to 150 in the larger, and Messrs. Fraser & Chalmers are prepared to build them to pump against a head of 3,000 feet in one lift.

FIG. 105.



RIEDLER EXPRESS PUMP.

A large number of these plants are working satisfactorily, especially on the Continent, and one of the best examples is at the works of the Mansfield Copper Company in Germany. This is the largest electrical installation in Germany, and consists of four Express pumps each with a capacity of 1,100 gallons per minute against a head of 1,430 feet when running at 176 revolutions per minute. The pumps are direct coupled to motors, and are of the two-throw type, single acting, with plungers $9\frac{7}{8}$ inches diameter and $13\frac{3}{4}$ inches stroke. The pumps are driven by two engines, each of 1,300 I.H.P., direct coupled to generators, the total I.H.P. of the plant thus being 2,600 I.H.P.

Fig. 105 is an illustration of a direct coupled two-throw Express pump.

Belt- and Rope-driven Pumps.—Where the conditions are suitable, this is probably the best method for the majority of mining pumps, the reason being that the belt takes up the shock to a great extent when starting the pumps, and is noiseless.

In the larger sizes a double-belt drive may be employed, with belt wheels and gearing at each side of the pump, as in fig. 104. Ropes are often preferred to belts. The belt pulley is always on the motor shaft, driving a large wheel on the countershaft, a pinion on this shaft gearing into a wheel on the crank shaft,

Size of Pumps Required.—In calculating the work to be done, due allowance must be made for the friction in the gearing of the pump, for friction of the water in the pipes, and for slip of water owing to the valves not working instantaneously.

Example.—Required, the size of rams and stroke of a three-throw pump capable of delivering 500 gallons per minute, with a head of 400 feet, and also the E.H.P. of motor to drive the same.

Allow 15 per cent. for slip and assume a ram-speed of 100 feet a minute, then each pump-ram moves 50 feet a minute against the load, and

$$\text{Gallons per minute} = \text{area (sq. ft.) of one ram} \times \text{number of rams}$$

$$\times \text{ effective speed of rams (ft. per minute)} \times 6{\cdot}25 \times \frac{85}{100} \text{ (slip)};$$

$$\therefore \frac{{\cdot}7854d^2 \times 3 \times 50 \times 6{\cdot}25 \times 85}{100} = 500.$$

$d^2 = {\cdot}8$ sq. ft. $\qquad d = {\cdot}9$ ft., say, 11 inches.

Three 11-inch rams

Stroke, say, twice diameter of ram = 22 inches.

$$\text{Revolutions per minute of crank shaft} = \frac{100}{\frac{22}{12} \times 2} = \text{about } 28.$$

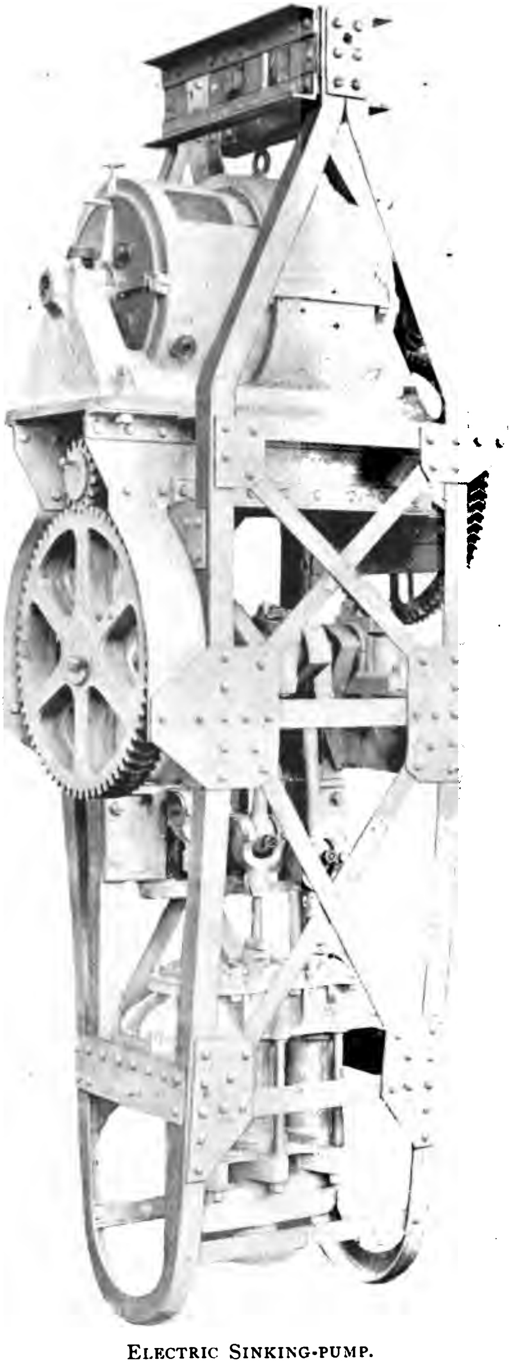
$$\text{h.p.} = \frac{\text{head} \times \text{quantity}}{33{,}000} + \text{friction of pumps and motor, say, 50 per cent.}$$

$$= \frac{5{,}000 \text{ (lbs. per minute)} \times 400 \text{ (feet of head)}}{33{,}000} \times 1{\cdot}5.$$

= say, about 100 E.H.P. motor.

A rough but effective rule is : h.p. of motor = h.p. in water lifted × 2.

FIG. 106.



ELECTRIC SINKING-PUMP.

Efficiency of Electric Pumping Plant.—The rope-driven electric generating plant described on page 81 is used to drive pumping plant as follows :—

The cables from the dynamo terminals to the pumping shaft consist of four overhead conductors of bare copper wire, each conductor being composed of nineteen strands No. 11 S.W.G. wire.

The shaft cables to the pumps are each 450 feet in length, and each cable is composed of sixty-one wires, No. 13 S.W.G.

There are two sets of main-shaft pumps, three-throw type, with rams 11 inches diameter and 18 inches stroke, driven by separate motors by means of cotton driving ropes.

This plant was tested at the same time as the generating plant, and the results obtained were as follows :—

Speed of pumps, 24 revolutions per minute.
Average E.H.P. at dynamo terminals, 140.
Average E.H.P. at motor terminals = 67 + 65 = 132.
Average B.H.P. at motor pulleys = 61 + 59 = 120.
Loss in cables, 8 E.H.P = 5·7 per cent.
Water delivered, 980 gallons per minute.
Horse-power in water lifted, 102.

Efficiencies :

$$\frac{\text{h.p. in water lifted}}{\text{E.H.P. at dynamo terminals}} = \frac{102}{140} = 72\cdot7 \text{ per cent.} \left\{\begin{array}{l}\text{Efficiency of}\\ \text{transmission.}\end{array}\right.$$

$$\frac{\text{h.p. in water lifted}}{\text{E.H.P. at motor terminals}} = \frac{102}{132} = 77\cdot4 \text{ per cent.} \left\{\begin{array}{l}\text{Efficiency of}\\ \text{motors and pump.}\end{array}\right.$$

$$\frac{\text{B.H.P. at motor pulley}}{\text{E.H.P. at motor terminals}} = \frac{120}{132} = 91 \text{ per cent.} \left\{\begin{array}{l}\text{Efficiency of}\\ \text{motors alone.}\end{array}\right.$$

$$\frac{\text{h.p. in water lifted}}{\text{B.H.P. at motor pulley}} = \frac{102}{120} = 85 \text{ per cent.} \left\{\begin{array}{l}\text{Efficiency of}\\ \text{pumps alone.}\end{array}\right.$$

This shows a good efficiency for the transmission, motor, and pumping plant.

Electric Sinking-pumps.—Electricity can very conveniently be applied to driving sinking-pumps. The chief advantage is that there is no exhaust to deal with, as would be the case if steam pumps were used, also the cable is much lighter and more easily supported than a range of steam pipes would be. Fig. 106 shows an electric sinking-pump made by Messrs. Easton & Company, of Erith.[1] This pump has three barrels, each 5¾ inches diameter, arranged for a stroke of 7 inches, and the gearing and motor are of sufficient power to enable the pump to deliver 5,500 gallons per hour against a head of 370 feet. The whole is supported on a strong mild-steel framing. The motor is of the enclosed four-pole type and runs at a speed of 950 revolutions per minute.

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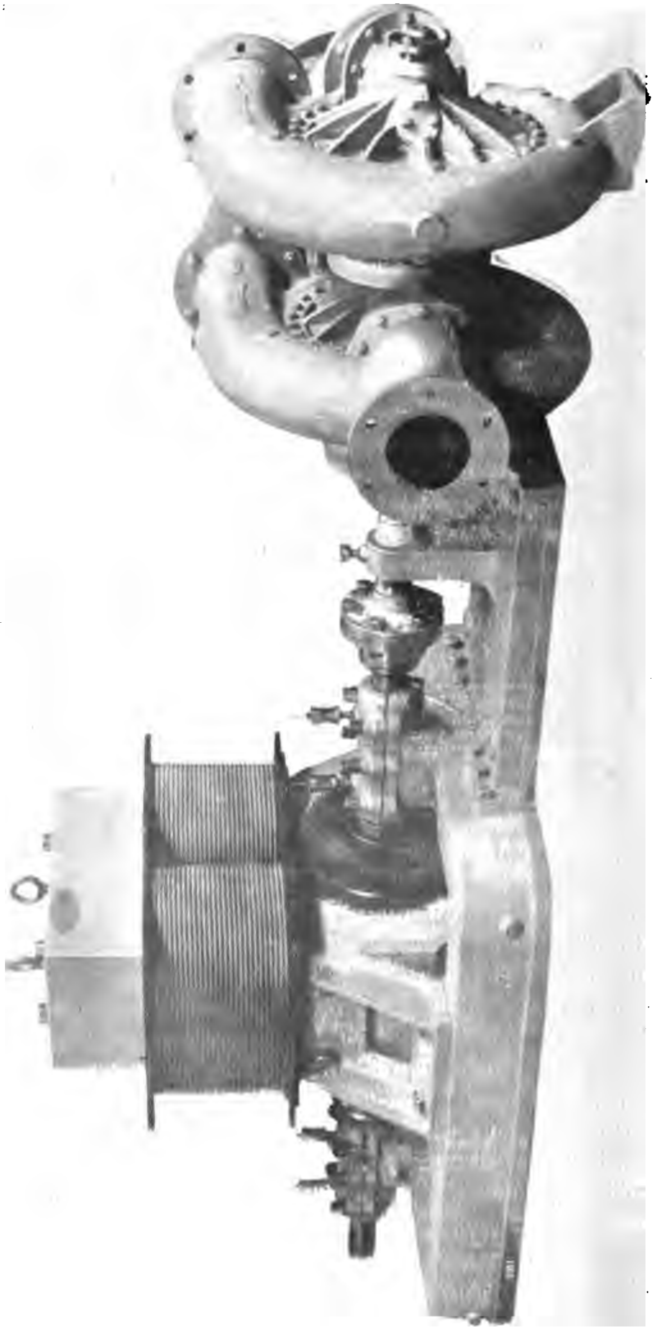
[1] The Sandycroft Foundry Company, near Chester, also make electric sinking-pumps of this type.

Fig. 107.



Electric Motor and Centrifugal Pumps in Series.

Centrifugal Pumps.—Electric motors are admirably adapted for driving centrifugal pumps, as the armature shaft can be coupled direct to the pump shaft. These pumps are very portable, and they have the advantage of being able to deal with dirty and gritty water, which would ruin the working barrels of an ordinary pump. For this reason they are very often applied to coal-washing plants, where the water needed for washing is raised to the top of the washer and used over and over again.

They are not so efficient as ordinary pumps except for very low lifts, as there is a great deal of slip, which increases as the height of lift increases, and they are not very often used for heads over 50 feet, though occasionally used up to 150 feet. A great length of suction is unsuitable. Two or more pumps may be coupled in series with each other, and so the total head increased. Fig. 107 shows an electric motor coupled to two centrifugal pumps.

The electric motor is also suitable for direct coupling to high-speed rotary pumps.

Electric Haulage.—Electricity is now widely employed as a means of driving the various forms of haulage machinery found in or about the mine. The use of slow- and fast-moving band-ropes worked by an engine on the surface and carried down the shaft to the haulage drums in the mine continues to find very great favour, however, and there are in operation haulage plants on this system which are worked at a less cost than would be the case if electricity were employed; the workings, however, have been laid out specially with the idea of using wire-rope transmission.

The methods of electric haulage may be divided as follows :—

1. Single-rope haulage drums worked by electric motor.
2. Main- and tail-rope drums worked by electric motor.
3. Endless-rope drums worked by electric motor.
4. Electric locomotives.

Single-rope Haulage is applicable when the coal-face is to the dip of the shaft, the empty trains running inbye under the influence of gravity and the full train being hauled up the incline by means of a drum.

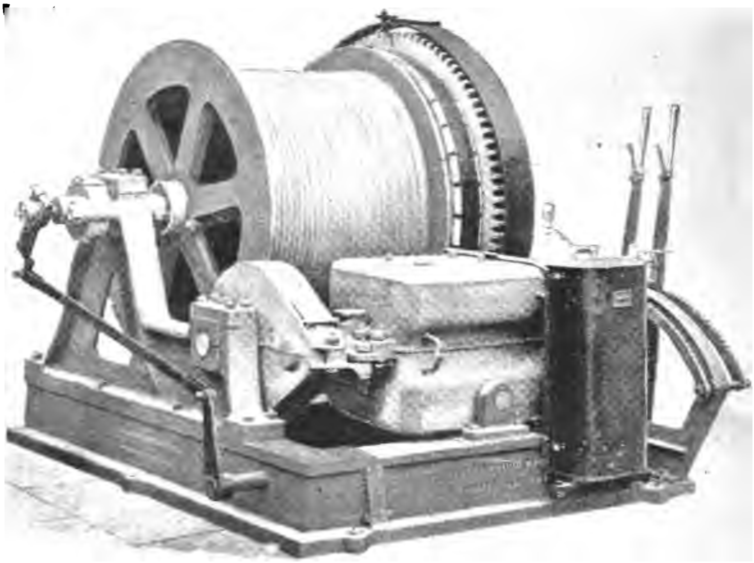
Such haulage gears may run at a high speed, ten miles per hour being attained if the roads are well laid out.

If a motor of moderate speed were adopted running at, say, 250 revolutions per minute, it could be coupled to the drum by means of spur-gearing with only one reduction.

The adoption of a slow-speed motor (though more expensive than high-speed) is advisable on account of the frequent stoppages required, as the windings of the armature are not subjected to so much strain, and so there is less liability to damage the insulation. If a high-speed motor is used—say, 500 to 700 revolutions a minute—then two reductions of speed may be required.

Where there is only a single reduction of speed, this cannot always be done effectually by means of a belt or rope-gearing, as in the case of a heavy load a long and heavy belt would be necessary. But where there are two reductions of speed, then a belt is generally preferred for several reasons. One is that the elasticity of a belt has a tendency to reduce shocks, which is beneficial to all parts of the machinery, and especially to the electric motor; and the other is that the belt works silently, whereas high-speed gearing, where metallic wheels are used, makes a deafening clatter. The noise may be minimised by the use of a raw-hide pinion in cases where it is suitable for the amount of work. In some cases the speed is reduced by means of a worm and worm-wheel. By this means the necessary reduction of speed can be got with one reduction and with a silent gearing. The objection to this form of gearing is that from its nature there is always a great deal of friction, the worm rubbing upon the teeth of the wheel, whereas in properly designed spur-gearing there is no rubbing, only a rolling contact. The difference between the two kinds of gears is illustrated by the consideration that well-designed spur-wheels may be run without any grease on the teeth, and with these teeth quite rough

FIG. 108.



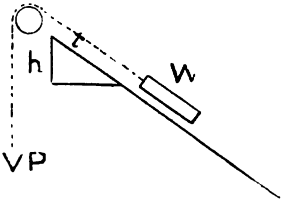
BRITISH THOMSON-HOUSTON SINGLE-ROPE HAULING DRUM.

to the touch, whereas no mechanic in his senses would start a worm to work against the teeth of a wheel that was rough to the touch or without lubrication. The difference is similar to that between a carriage on wheels and a sledge. A sledge, however, may run upon a smooth surface such as ice, and similarly worm-gearing may act satisfactorily if sufficiently well lubricated, and if the surface in contact is sufficient to prevent too heavy pressure at the points of contact so as to drive out the oil from between the rubbing surfaces. In no case is worm-gearing as economical as spur-gearing, but there may be cases where loss of power may be tolerated for the sake of convenience and economy in first cost (though it must be borne in mind that economy in first cost at the motor must not be purchased by a greater outlay at the generator).' Worm gearing must work in a bath of oil, and the oil should be constantly led away to a filter, so that all metallic and other grit may be removed before it is returned to the oil-bath.

Fig. 108 shows a British Thomson-Houston electric hauling drum for use with a direct-current motor, fitted with a patent friction drum and brake. The drum is loose on the shaft and engages with a double-cone friction by a small end movement along the shaft.

The work to be done in hauling a train up an incline is soon calculated. Referring to fig. 109, it will be seen that if a weight, W, is pulled up an incline by a pull, P, acting parallel to the incline, the distance on the incline being called l and the vertical height corresponding to that length being called h,

FIG. 109.



$$P \times l = W \times h$$

and

$$P = \frac{W \times h}{l}.$$

Thus, on an incline rising 10 feet vertical in 100 feet measured on the slope, the pull on the rope in pounds for a weight of 1 ton would be

$$P = \frac{2{,}240 \times 10}{100} = 224 \text{ lbs.}$$

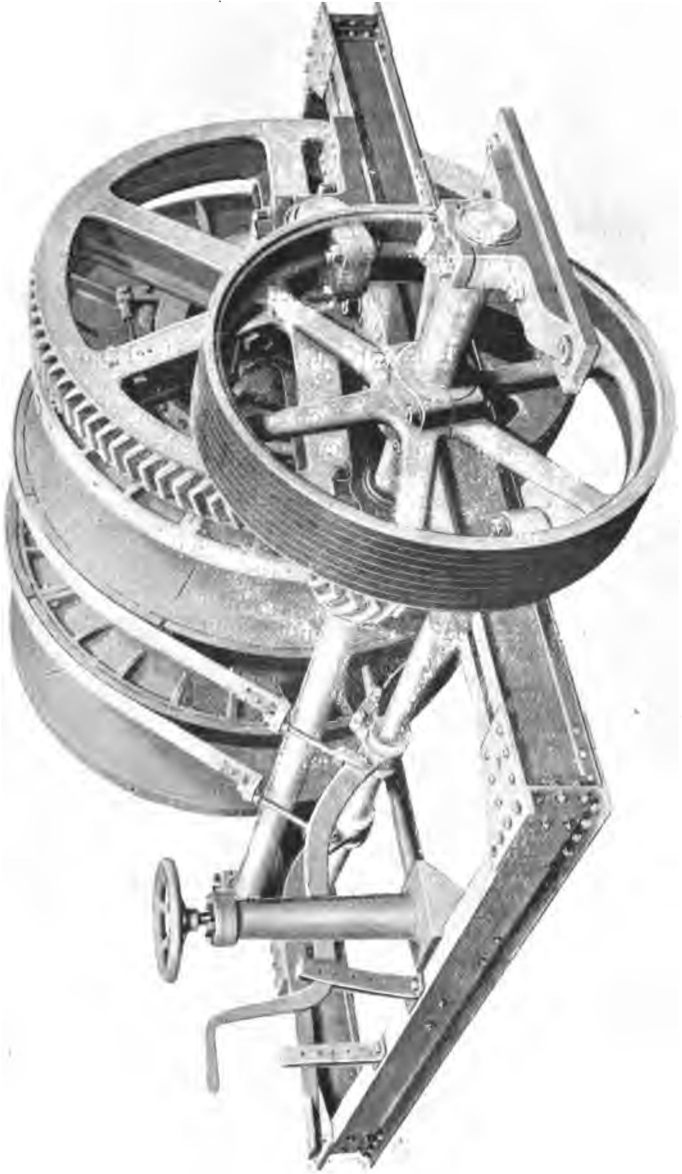
To get the total load the friction of the tubs and rope must be added; these vary with the conditions, and can be found experimentally.

TABLE SHOWING STRAIN ON ROPE TO BALANCE DEAD WEIGHT AT VARIOUS INCLINATIONS.

Elevation (vertical) in 100 feet (horizontal)	Corresponding Angle of Inclination	Strain on Rope for a Load of 1 ton
Feet	°	Lbs.
5	2⅛	125
20	11⅓	452
40	21⅝	843
70	35	1,293
100	45	1,587
150	56⅓	1,872
175	60¼	1,952

The dead weight to be lifted includes the coal or stone, tubs, and rope, and the friction of this may be roughly stated at 5 per cent. for a straight road. The friction of the gearing, consisting of two reductions of speed by spur gearing, or of one reduction by belt and one by gearing, may be roughly put at 20 per cent. In order to get up speed rapidly there must be a considerable margin of power in the motor to impart the necessary velocity to all the moving parts, and this should be not less than 25 per cent. of the load; therefore, the power of the motor should not be less than 50 per cent. in excess of the maximum pull required merely to hold the load stationary on the incline. When we come to deal with crooked roads, and with the main and tail rope and endless rope, the friction of the rope is very much increased, and the amount of the increase depends to a great extent upon the care with which the wheels and rollers to carry the rope are constructed, arranged, and lubricated; and it sometimes happens that the power of the motor required to do the work with ease is three or four times as much as would be sufficient simply to overcome the weight and friction of the train. Where there is a heavy load on a steep incline it is much easier to calculate the size of motor necessary, because here the weight is the chief consideration, and the pull to balance that can be easily calculated; but in the case of a long and crooked road, worked main and tail, with a gradient very slightly against the load, or level, or even in favour of the load, it is often difficult to foresee what amount of power will be absorbed in friction; and cases have been known where a 50-h.p. motor was required to haul a load on the main and tail system at the rate of six miles an hour, the road being practically level, though undulating in places, but nowhere steeper than 1 in 20, the total weight of train and rope not exceeding 20 tons. It must be borne in mind that the great secret of satisfactory working of electric motors for haulage is to have them big enough, as then there is less strain and heating. The writers have known cases where, according to a liberal calculation, a 25-h.p. motor would be sufficient, and yet in practice a 35-h.p. motor was barely sufficient, and a 50-h.p. motor was found to

FIG. 110



MAIN- AND TAIL-ROPE HAULING DRUMS.

give the most satisfactory results, the extra power being required to overcome the friction of the rope in passing round curves; but there cannot be the least doubt in the mind of any mechanical engineer that if sufficient care had been taken and sufficient expense incurred in the construction, arrangement, and lubrication of the rollers and pulleys, the friction might have been very greatly reduced; but in the instance above alluded to the result was obtained with such skill and care as an ordinarily good colliery engine-wright and manager are capable of giving.

Main- and Tail-rope System.—With a varying gradient the set must be pulled both inbye and outbye, and consequently two drums are required.

A plan frequently adopted for large installations is to drive by means of two motors, either of which in case of a breakdown could work the plant with a smaller load on. This method, where space permits, is an admirable one.

A main and tail rope haulage plant, with rope wheel and spur gearing, is shown in fig. 110.

In calculating the power required on this system the heaviest gradient on the road is taken, and, in addition to the friction of tubs and main rope, the friction of the tail rope must be considered.

Endless-rope System.—This is essentially a slow-running continuous plant, and it follows that where it is applicable the amount of work to be done is much more equally distributed, and consequently the motors may be of smaller power The speed of hauling rope is usually about two miles per hour, consequently a high ratio of reduction is necessary.

With spur gearing three reductions are usually required, but by driving from the motor with ropes or a belt, one set of spur-wheel and pinion is dispensed with. The strain on the motor, however, is much more uniform, and there is not the same necessity for a rope-drive as in the case of main and tail. Fig. 111 illustrates a type of endless-rope driving gear in which the speed is reduced by worm gearing.

The majority of haulage plants in operation are on the continuous-current system, but poly-phase (generally three-phase) current is also employed.

At the Park Colliery, Garswood, and the Sandwell Park Colliery, near Birmingham, three-phase plants have been erected by the Corlett Engineering Company, of Wigan. The special feature of the poly-phase system is that the motors can be taken very near the working face without danger from sparking, and used for the secondary haulage between the face and the main haulage planes.

At the Park Colliery the plant consists of a three-phase generator. The voltage is 500, and the current 80 ampères in each phase. The periodicity is 40 per second, and the speed 400 revolutions per minute. The exciter is a small four-pole continuous-current machine, shunt wound for a voltage of 75. The motors include one of 35 h.p., working a haulage plant; one of 10 h.p., working a pump and haulage alternately; and six of 4 h.p., five of which are driving pumps, and one a small hauling drum.

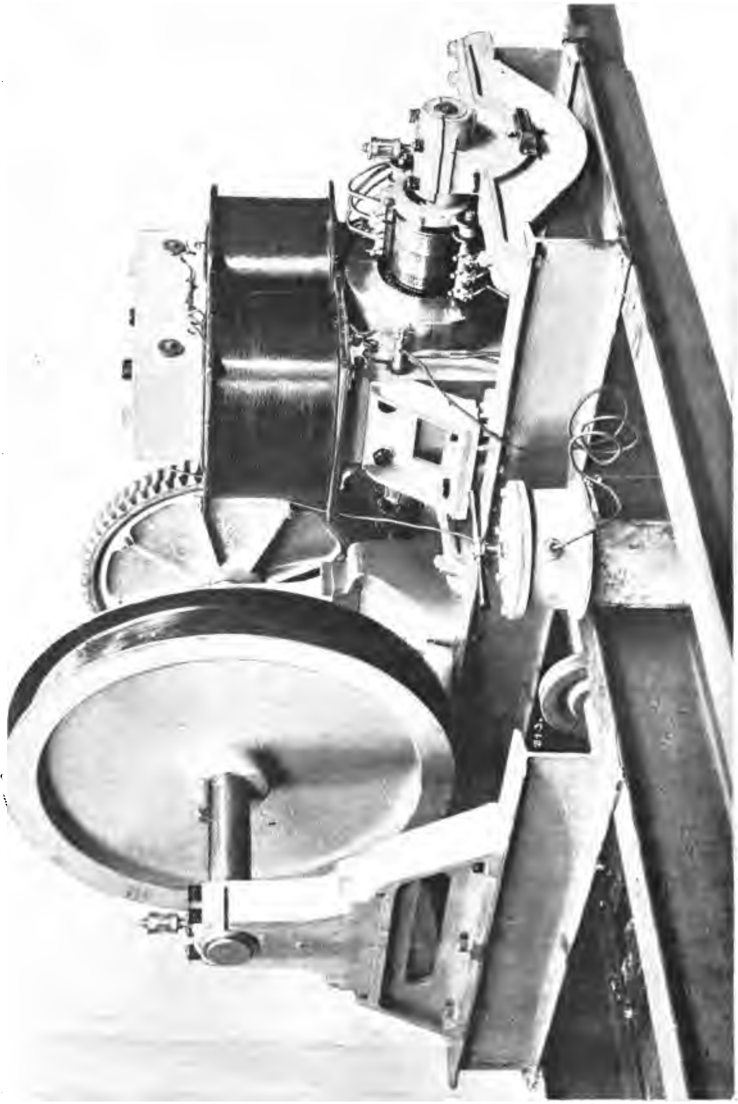
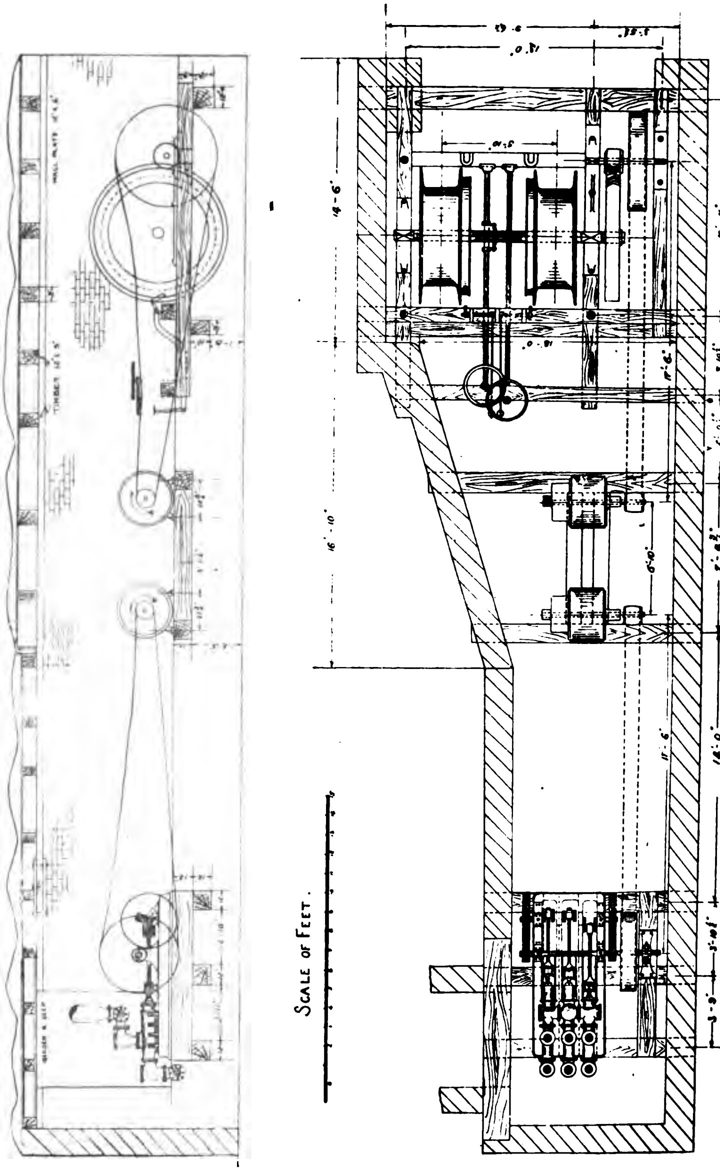


FIG. III.

ENDLESS-ROPE HAULAGE PLANT DRIVEN THROUGH WORM GEARING BY AN ELECTRIC MOTOR.

The motors are all of the induction type, deriving their motion from the revolution of the magnetism of the field poles (these poles themselves being stationary). The armature shaft is provided with slip-rings for the purpose of connecting the starting resistance. These poly-phase motors will stop with an overload of about 15 per cent.

FIG. 112.



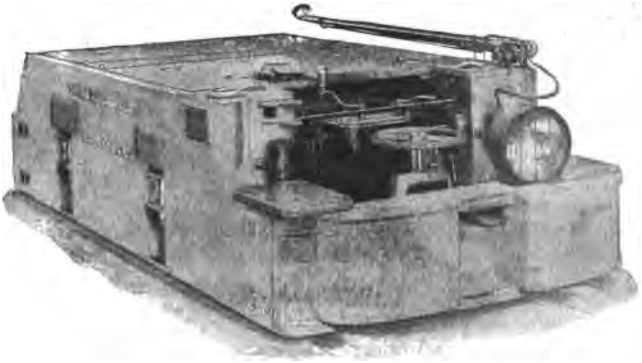
UNDERGROUND ENGINE HOUSE, WITH THREE-THROW PUMPS AND MAIN- AND TAIL-ROPE HAULING DRUMS **(Sandycroft Foundry Company, Ltd., near Chester).**

Fig. 112 is reduced from a working drawing, and shows a good arrangement of pumps and hauling drums in one engine-house, by the Sandycroft Foundry Company Chester.

Electric Locomotives.—In some European and in some American mines electric locomotives are used for haulage. In this country, however, the use of electric locomotives underground has been so far confined to a few mines. Their chief disadvantage for low roads, or gassy pits, is that the cables required are not insulated. The motors take their current from a bare overhead wire, and the circuit is completed through the rails. This entails a certain amount of sparking, and also involves a risk of electric shock.

The great weight of the locomotive also entails an expensive road, with heavy rails and sleepers, as the consequences of the train getting off the road might be very serious.

FIG. 113.



ELECTRIC LOCOMOTIVE.

For long distances, where the roads are crooked and the gradients suitable, electric locomotives would possibly be more efficient than wire-rope haulage. The main objection to locomotives in a pit is the uncertainty of the gradients and the fact that locomotives are not well adapted for gradients steeper than 1 in 50. In America there are many mines worked from levels driven in the hillside, and here the locomotive used on the surface is run into the mine as the gradients and other conditions allow.

Continuous current is usually employed, the weight of the locomotive being from 2 to 20 tons, the height of the smallest locomotive, excluding the trolley, being 36 inches, and that of the heavy locomotive 46 inches, a usual speed being from eight to ten miles an hour.

Fig. 113 shows a British Thomson-Houston standard 8-ton electric mine locomotive.

CHAPTER X

ELECTRICITY APPLIED TO COAL-CUTTING

Pick Machines—Revolving-bar Machines—Disc Machines—Chain Machines.

ONE of the most important applications of electricity to mining work, and one in which there is great room for development, is the driving of machinery for under-cutting coal to supersede the ordinary method of 'holing' by hand.

The advantages of machine-holing as compared with hand-holing may be summarised briefly as follows:—

(1) A greater proportion of round coal, owing to the reduction of the width of the holing, and owing to the greater distance the coal is under-cut. With a machine-cut the width of the holing will be uniform from 4 inches upwards, but with hand-holing the width will vary with the depth of the under-cut, because it is necessary for the workman to cut away sufficient coal to enable him to get underneath it, so that the width will vary from about 21 inches at the front down to nothing at the back.

(2) The rate of advance of the face can be greatly accelerated. This is an important consideration in seams with a tender roof, and exposes the workman to less risk.

(3) The machine-holing produces a straight line of cut, and this induces a straight line of fracture in the roof, and in this way a more systematic arrangement of timbering can be used than when hand-holing is practised.

(4) The coal is very easily and safely spragged.

(5) The cost of working is greatly reduced (where conditions are favourable to its use), and, owing to the greater output, the quantity of coal raised per man is much greater, and in many cases the wages earned are higher, than when holing by hand.

(6) The increased rapidity with which the face is advanced enables a large tonnage to be got from a shorter length of face, and so reduces the length of roads to be kept open.

In the year 1900 the Home Secretary was furnished by the inspectors of each district with a return of the proportion of coal-cutting machines in use, and from the inspectors' reports the table on page 179 has been compiled.

NUMBER OF COAL-CUTTERS IN USE IN THE UNITED KINGDOM IN THE YEAR 1900.

District	No. of Coal-cutters		Tons of Coal Wrought
	Compressed Air	Electric	
South-Western	2	—	10,000
East Scotland	32	1	297,290
North and East Lancashire	9	8	86,000
Newcastle	12		150,000
Yorkshire	67	16	1,046,941
South Wales	10	—	Not stated
South Staffordshire	—	6	40,707
Midland	43	28	645,685
Liverpool	44	2	500,000
West Scotland	12	—	232,500
Durham	10	5	192,504
North Staffordshire	6	3	43,880

From this table it will be seen that on January 1, 1901, there was a total of 316 coal-cutters in operation, which had mined over three and a quarter million tons in the year 1900, or 1¾ per cent. of the total output for the United Kingdom. The number in use at the end of 1901, as given in Dr. Foster's report, was 345. In America the value of the coal-cutter has been more fully recognised, and it is estimated that there were in use, in twenty-two States, in 1900, 3,907 machines, mining 19·6 per cent. of the total output of the country, both anthracite and bituminous.

As the thicker seams in this country are exhausted, the use of the coal-cutter will undoubtedly very largely increase, as it affords an opportunity of working at a low cost seams impossible to work at a profit by hand-holing.

The motive power for coal-cutting machines is limited to electricity and compressed air, as will be seen from the above table, and compressed air has been up till quite recently the chief means of transmitting power from the surface to the face. As in drilling, however, so in coal-cutting, the great loss with compressed air arises from leakages in the pipes, which prove very expensive. A great deal of time, also, is taken in laying the pipes and in coupling to the machine. With electricity the cables are easily laid along the gates and the coal face, a greater speed of cutting can be attained, and when the machine is not working no power is being consumed.

Electric coal-cutters can be divided into the following classes:—

(1) Pick machines, in which the coal is chipped away in a similar manner to that employed by the miner.

(2) Revolving-bar machines, in which a number of teeth are fixed on the circumference of a rapidly-revolving bar.

(3) Disc machines, in which teeth are fixed on the circumference of a horizontal wheel.

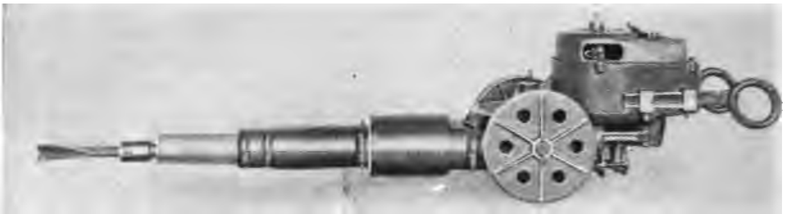
(4) Chain machines, in which the cutters are fixed on an endless chain.

(1) **Electric Pick Machines.**—Although there are several success-

ful compressed-air pick machines, amongst others the Yoch and the Ingersoll-Sergeant, there has so far been very little development in the electrical pick machines, there being only one at present on the market.

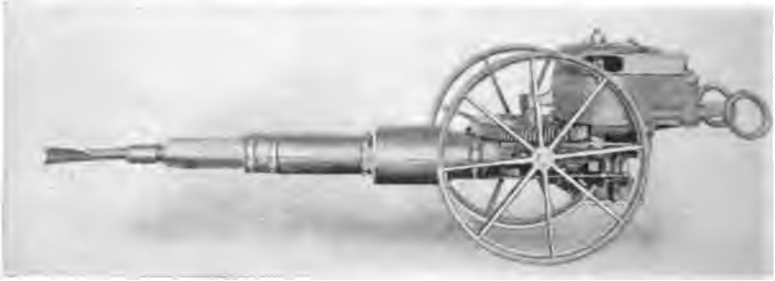
The Morgan-Gardner Electric Pick Machine.—This machine, shown in figs. 114 and 115, has a reciprocating piston actuated by a spring and cam, the spring striking the blow and the cam drawing the piston back. The cam is driven by an electric motor.

FIG. 114.



MORGAN-GARDNER ELECTRIC PICK MACHINE, AS USED FOR UNDER-CUTTING.

FIG. 115.



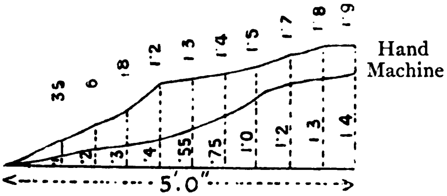
MORGAN-GARDNER MACHINE, MOUNTED ON HIGH WHEELS FOR SHEARING.

The stroke of piston is 8 inches, and runs from 175 to 225 strokes per minute. The length of the machine is 7 feet; the width over the wheels is 21 inches, the weight being 750 lbs.

This class of coal-cutter is popular in America, and is, of course, particularly adapted to pillar and stall working. The method of working is to place the machine on a board about 6 feet long and 3 feet wide, which is raised at the back so as to give the board an inclination of 4 or 5 inches to the yard towards the face. The machine-man sits behind the coal-cutter, with a hand on each handle, and the recoil is taken up by the inclination of the board, and by a leather buffer and air cushion at the back end of the cylinder. The speed of under-cutting is estimated at from four to six times that attained by hand. The pick machine makes less slack than ordinary hand-holing.

Fig. 116 shows a section of the coal-face, with the comparative height of hand-holing, and that of the pick machine,[1] from which it will be seen that the latter makes 30 per cent. less slack than hand-holing. The chief advantage of the machine seems to be that it is light and easily moved.

FIG. 116.



(2) **Revolving-bar Machines.**—The most successful type of this machine is the Hurd Coal-cutter, manufactured by Messrs. Mavor & Coulson.

The Hurd Coal-cutter.—This machine consists essentially of five parts: (1) Cutter-bar, (2) gear-head, (3) motor, (4) switch-box, (5) hauling gear. The cutter-bar is made of mild steel, and is tapered towards the end; it has a spiral thread, and conical holes to receive the cutters are drilled on the thread and also between the threads. By fixing the cutters on the thread a greater width of holing can be got; if a less width of holing is wanted, the cutters are fixed between the threads.

The arrangement of gearing will be seen in figs. 117 and 117A. The motor shaft, which has a bevel wheel, *a*, on the end, projects into the gear-case and drives the upper bevel wheel, *b*, on the vertical shaft, the reduction in speed being 2 to 1. The lower bevel wheel, *c*, on the same shaft engages with a pinion, *d*, which drives the bar. A reciprocating motion is given to the bar by means of a worm, *w* (see fig. 118), on the boss of the bar-driving pinion, gearing into two small wheels, *e* and *f*, each of which drives a toggle by means of an eccentric pin. The toggles impart a to-and-fro movement of about 2 inches to the thrust-block, *g*, which is communicated to the cutter-bar, there being a feather on the latter which enables it to pass to and fro within its driving pinion. The rack, *h* (figs. 117, 117A), on the lower part of the gear-case, in conjunction with a pinion not shown in the illustration, enables the lower part of the gear-head with the cutter-bar to be revolved in a horizontal plane round the vertical axis; by this means the machine can be made to cut its way into the coal at starting, and also the cutter-bar can be brought out for the purpose of renewing the cutters.

The complete machine is shown in fig. 119, and it will be seen that

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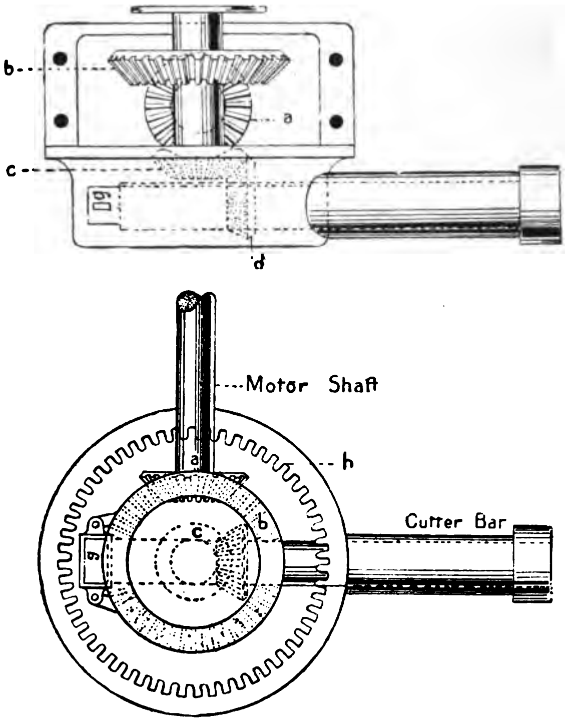
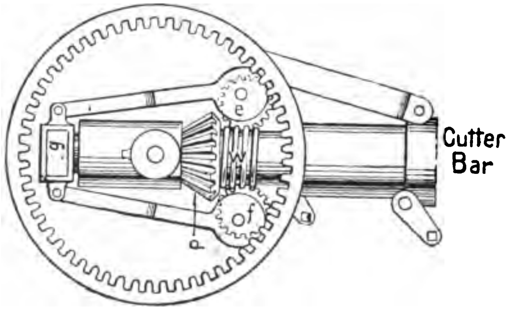
[1] 'Coal-cutting by Machinery,' by Mr. W. Blakemore; *Transactions Inst. Mining Engineers*, xi. 179.

FIGS. 117 and 117A.



GEARING IN HURD ELECTRIC COAL-CUTTER.

FIG. 118



RECIPROCATING MOTION OF BAR. HURD COAL-CUTTER.

the bar can also be revolved in a vertical plane by means of a worm and worm-wheel. The haulage gear is worked by a worm fixed at the end of the armature shaft, and is of the usual pawl and ratchet-wheel type.

The electric motor may be either continuous- or alternating-current, but the majority of the machines at work are on the continuous-current system, with series-wound motors and carbon brushes. The machines are made in three standard sizes, as follows :—

—	Small	Medium	Large
Extreme length	6 ft. 6 in.	9 ft. 3 in.	9 ft. 6 in.
,, width	2 ft. 6 in.	2 ft 8 in.	2 ft. 8 in.
,, height above rail	1 ft. 1 in.	1 ft. 4 in.	1 ft. 10 in.
Weight of machine	19 cwt.	30 cwt.	45 cwt.
,, ,, bar	1½ cwt.	2½ cwt.	3 cwt.
Depth of undercut	2 ft. 6 in. to 3 ft. 6 in.	3 ft. to 4 ft. 6 in.	4 ft. to 6 ft.
Power of motor	12 B.H.P.	18 B.H.P.	26 B.H.P.
Pressure or voltage	400 volts	400 volts	400 volts
Gauge of rails	1 ft. 6 in. to 2 ft. 3 in.	1 ft. 9 in. to 2 ft. 4 in.	2 ft. to 2 ft. 4 in.
Weight of rails	22 lbs. per yd.	25 lbs. per yd.	28 lbs. per yd.

The speed of the bar is from 400 to 500 revolutions per minute, which necessitates only one reduction in gearing, and consequently absorbs less power in driving than a machine requiring a double reduction. One great advantage is that the coal, after being under-cut, can be spragged close up to the bar and within a few inches of the solid coal ; while with the disc machine the sprags are necessarily as far off as the diameter of the wheel. The bar, also, is more readily recovered in case of a fall of coal.

At the Ackton Hall Colliery, Hurd machines are working very successfully in a seam of moderate thickness. On the occasion of a recent visit the machine was cutting 5 feet 8 inches under, the width of cut being 6 inches at the front and 5 inches at the back. An alternating-current motor of ample size drove the bar, and there was no difficulty in starting the machine. The rate of advance, as noted at the time, was 1 foot a minute, but according to the operator the usual speed of cutting was 1 yard in 2½ minutes, while in a run of 6½ hours, allowing for stoppages and laying rails, &c., 60 yards had been cut. The time taken to change the teeth (39 in all) was from thirty to forty minutes.

At a Staffordshire colliery[1] a machine under-cut to a depth of 3 feet 6 inches at a rate varying from 1½ to 2 feet a minute, and, counting stops, the rate was 24 yards per hour.

Modifications of the Bar Machine.—There have been many different types of bar coal-cutter, which have met with varying success. A machine recently described, called the 'Lee Coal-cutter,'[2] has one or two novel features. The ordinary form of haulage gear, consisting of a wire rope attached to the machine and carried round a pulley some distance in advance, is dispensed with, and in its place one of the rails on which the machine runs is notched like a rack, and the machine propels itself by means of two toothed wheels meshing with the rack bar. With this arrangement a straight face is not absolutely necessary. The cutters, also,

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[1] *Transactions Inst. Mining Engineers*, xvi. 449.

[2] 'An American Longwall Mining Machine,' by H. Foster Bain; *Transaction Inst. Mining Engineers*, xix. 144.

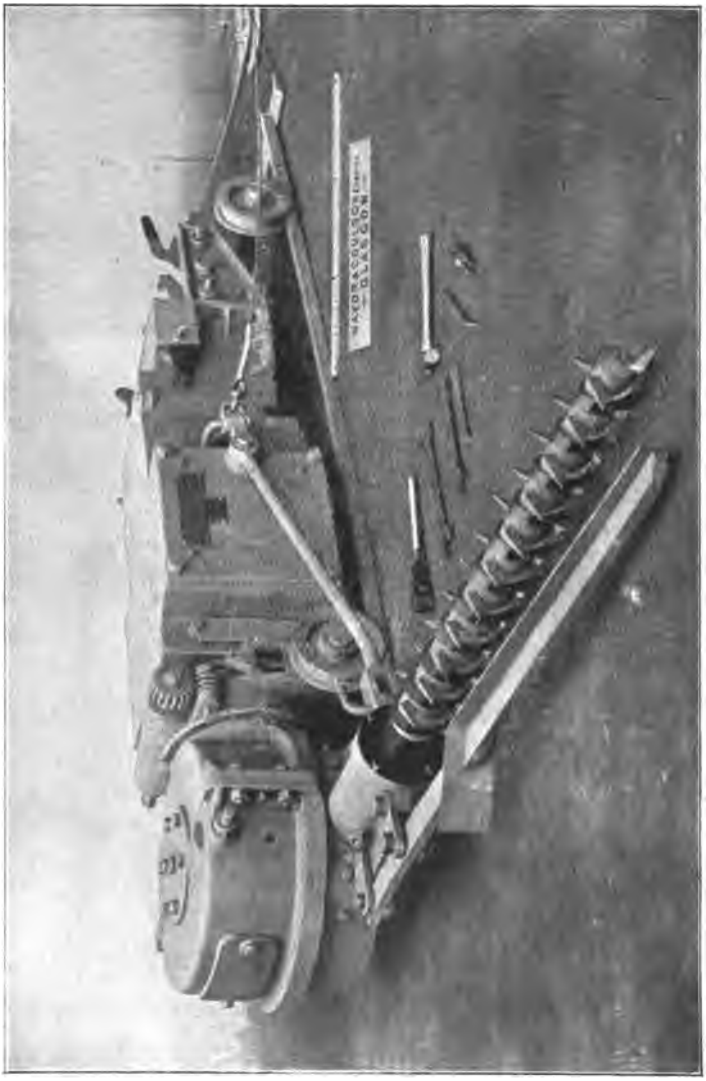


FIG. 119.

HURD ELECTRIC COAL-CUTTING MACHINE, ADJUSTED FOR UNDER-CUTTING.

instead of being held in holes drilled in the bar—which of necessity must weaken it—are carried on a spiral of tool steel, which can be slipped off the bar when the teeth are dull or worn out. The machine is said to have done good work at the Mystic Mine, Iowa, U.S.A., where twelve are at work under-cutting 2 feet 6 inches under in a seam 2 feet 6 inches thick.

Heppell and Patterson Coal-cutter.—This machine, which is also of the bar type, differs in important details from those already mentioned. The cutters are fixed in three dovetailed grooves in the cutter-bar ; they are kept in position and at the right distance apart by strips of metal, so that they can be arranged in any way desired. The *débris* from the cutter-bar is also brought out by means of a small endless-chain conveyor which works at the side of the bar, thus getting over one of the difficulties urged against the bar-cutter.

Jeffrey Bar Machine.—In this coal-cutter the bar, instead of working at right angles to the face, works parallel to it. It is driven from an electric motor by a chain belt and sprocket-wheel, and is carried on a frame which is gradually advanced into the coal as it is cut away by the bar. This machine is not largely used, having been superseded by the Electric Chain Machine (see page 192).

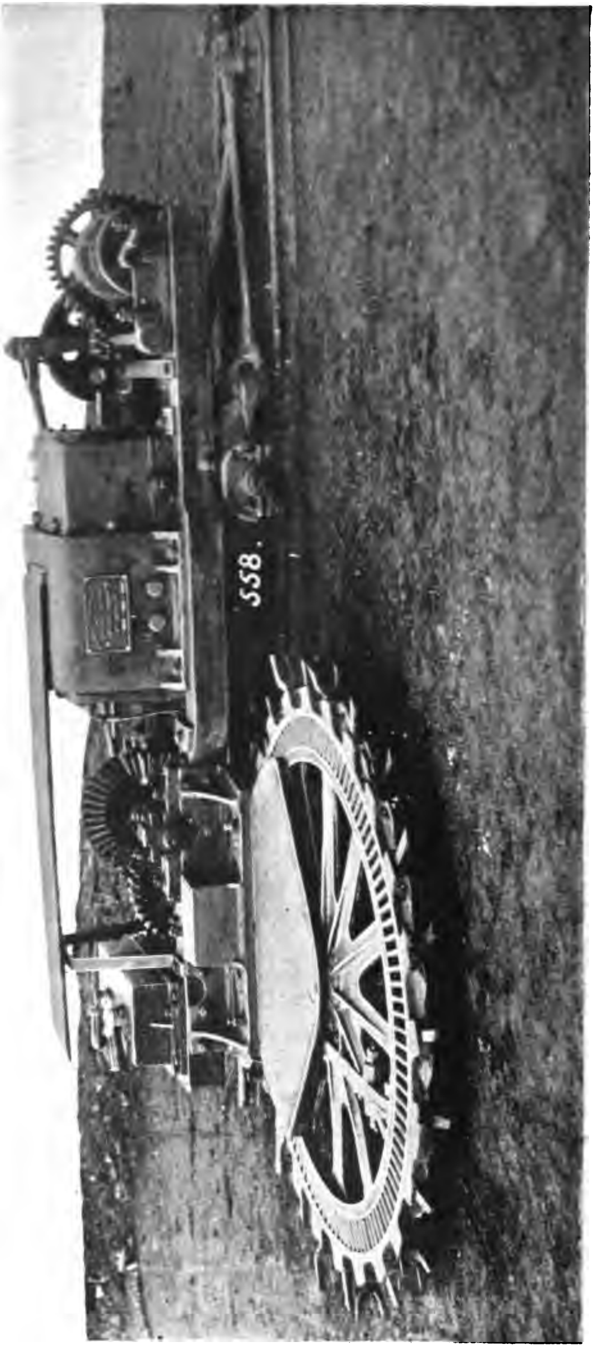
(3) **Disc Machines.**—This is the most popular type of machine in this country, and there are many varieties successfully working.

Clarke & Steavenson's Electric Coal-cutter.—This machine (fig. 120) consists of a continuous-current series-wound motor, on the armature shaft of which is a bevel pinion with 16 teeth, which gears into a bevel wheel on an intermediate shaft with 40 teeth. A spur wheel on this intermediate shaft with 13 teeth gears into another spur wheel on the driving shaft with 39 teeth, and at the end of this shaft a wheel with 18 teeth gears directly into the cutting-wheel, which has 125 teeth.

The advance of the machine is obtained automatically in the usual manner. A crank on the first-motion shaft is connected by a rod to a pawl or ratchet working on a toothed wheel; the throw of the crank can be varied so as to make the ratchet engage more or fewer teeth on the wheel. On the same shaft as the ratchet-wheel is a small pinion which drives a winch, and a steel-wire rope is taken from this round a pulley some 50 or 60 yards in advance and back to the machine. The cutting-wheel makes about 30 revolutions per minute, but, the motor being series-wound, the speed of course varies with the load. There are 20 cutters, 10 straight and 10 V-shaped, arranged alternately, and the width of cut is 4 inches.

The motor is enclosed in a gas-tight case, and is of 30 h.p.—the makers having found that the secret of success in coal-cutting lies in having a motor of ample size for the work to be done—the h.p. necessary to drive the machine in average ground being about 20. The motor is provided with a starting switch and a resistance to regulate the current. The

FIG. 120.



CLARKE & STEAVENSON'S ELECTRIC COAL-CUTTER.

machine is made in three sizes—No. 1, standard type, height from floor, 28 inches; No. 2, medium type, height from floor, 22 inches; No. 3, low type, height from floor, 20 inches. Three sizes of wheel have also been made—a 4-foot wheel, under-cutting 3 feet 6 inches; a 5-foot wheel, under-cutting 4 feet 6 inches; and a 6-foot wheel, under-cutting 5 feet 4 inches. The weight of the machine varies from 35 cwt. to 2 tons.

In a recent visit to Lidgett Colliery, near Barnsley, where several of these machines have been at work for some years past, the following notes were made, which will be of interest as showing what is actually being done by coal-cutters. The seam worked is of the following section :—

Good house coal	2 feet
Holing dirt	4 to 6 inches
Inferior coal . . .	9 inches

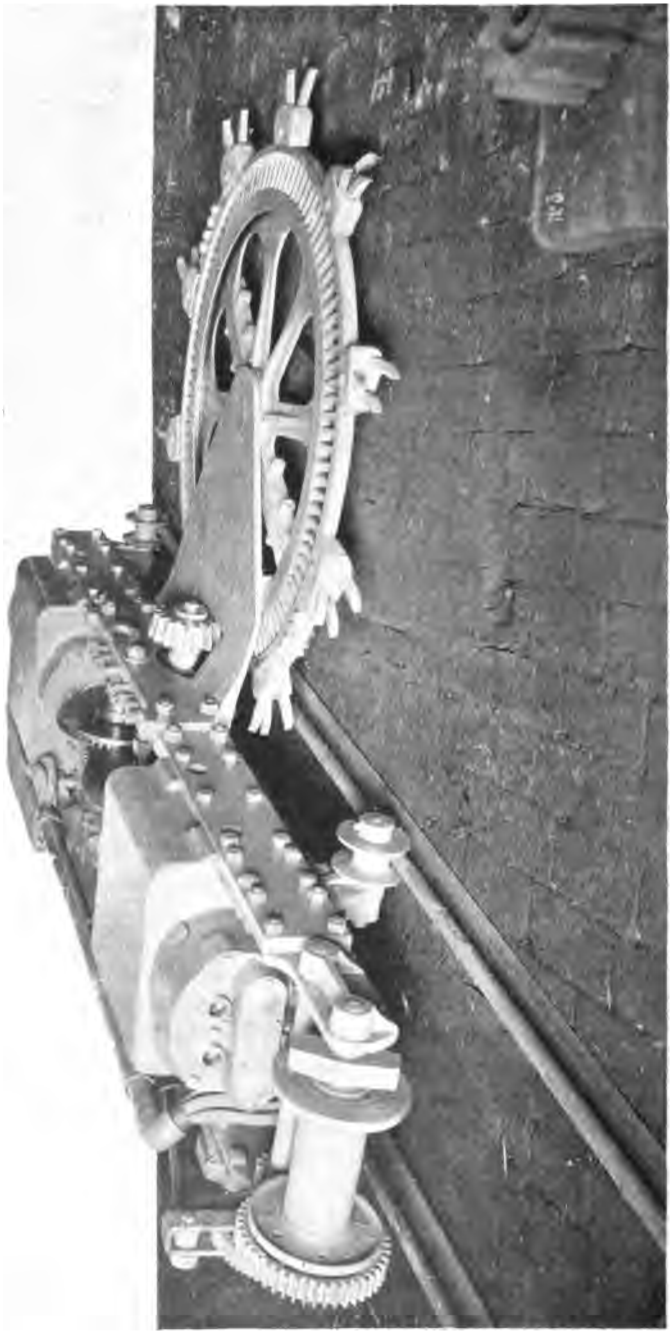
The cut is made in the holing dirt, and the collier gets up the bottom coal, part of which is sent out for consumption at the colliery, and the rest is thrown into the goaf. Two electric machines are at work, and these are both cutting at night, but only one during the day. The cutter-wheel is 4 feet diameter, with a 3-foot 6-inch under-cut. Two men operate the machine. The machines work on a face of 900 yards, gates are 22 yards apart, with cross-gates every 50 or 60 yards. One collier and a boy work in each stall. The whole length of 900 yards of face is cut in a week, and the machine is taken along the cross-gate and starts again at the beginning of the face. The cables supplying the coal-cutters are brought along the cross-gate and up every other gate to the face. Switches are fixed at each of these gate ends. The cables used are separate cables—not concentric.

The actual speed of cutting when the machine was seen at work was 4 yards in 5 minutes. It was stated that in a shift of 8 hours 80 yards has been cut; deducting snap time, &c., the actual time spent in cutting would be about 6½ hours.

Diamond Coal-cutting Machine.—This is another successful disc machine, very similar to that last described—that is to say, on the lines of the original Gillott & Copley machine. The design is largely due to Mr. W. E. Garforth, of the West Riding Collieries, Normanton, who has a very large experience of coal-cutting. He was the first to advocate a deeper under-cut, which has been the means of largely reducing the number of shots required to blow down the coal; besides which, of course, a smaller number of cuts is required for a given advance of face, so lessening the labour in timber-setting, &c.

The machine is illustrated in fig. 121. It will be seen that there are two motors, one on each side of the cutting-wheel; this, of course, increases the length of the machine somewhat, but that is immaterial in a long-wall face. The advantages of having two motors are—first, that the balance of

FIG. 121.

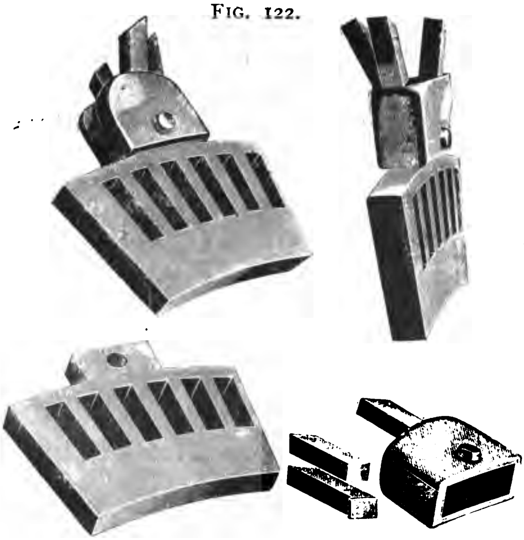


DIAMOND COAL-CUTTER.

the wheel is improved; and, secondly, that, owing to these motors being smaller than if only one were employed, the diameter of the armature is less, and a lower build of coal-cutter is obtained for very thin seams. The motors are from 10 to 12 h.p., and run at a speed of 750 revolutions per minute. When the voltage is below 200, the motors are connected in parallel, but above that voltage they are connected in series with each other.

Another admirable feature of the machine is the patent cutter-box (see fig. 122). The cutter-wheel has lugs on its circumference on to which the cutter-box fits; each box holds three teeth, and the number of boxes on the wheel varies with the size, the 5-foot 6-inch wheel having ten boxes, and the 7-foot 6-inch having fifteen.

FIG. 122.



DIAMOND COAL-CUTTER: CUTTER-BOX.

These cutter-boxes greatly expedite the operation of changing the teeth, and in thin seams, should it be required to cut both ways, this is done by simply reversing the motor and turning the boxes the other way round.

The speed of the cutting-wheel is from 10 to 15 revolutions per minute. The standard machine is made to hole to a depth of 5 feet 6 inches, and a width of 6 inches, the gross weight being 40 cwt., the weight without cutter-wheel and bracket being 30 cwt. The length of frame over all is 8 feet 6 inches; width, 3 feet 4 inches; and height from floor, 25 inches.

The smallest machine built so far has a height from the floor of 18½ inches.

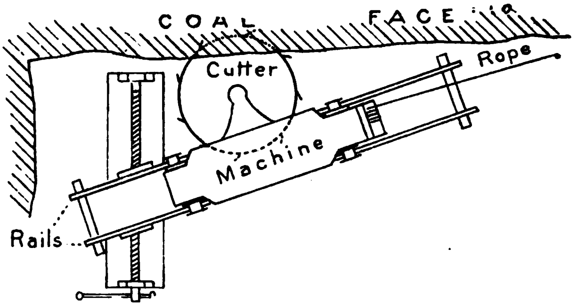
Fig. 123 shows an arrangement whereby the coal-cutter can be made to cut its way into the face when starting a cut.

At the Middleton Colliery,[1] near Leeds, two Diamond machines are employed in the Crow Coal, a seam which has only recently been opened out. The seam lies at a depth of 226 yards from the surface, and the section is as follows:—

Roof Blue Bind	
Coal	1 foot 6 inches
Holing dirt . . .	9 inches to 18 inches, very hard
Johnny coal . . .	6 inches

The coal is very tender, which necessitates it being got on the 'end,' the 'bord' faces which are necessary to open out are got by hand-holing, and the dirt is so hard that the holing has to be done in the coal, the yield from a 'bord' face being consequently practically all small coal.

FIG. 123.



DIAMOND COAL-CUTTER: 'CUTTING-IN' ARRANGEMENT.

The standard machine is used, with an under-cut of 5 feet 6 inches; voltage 300, continuous-current; the length of face on which each machine works being 260 yards, with gate roads every 40 yards. The main cable goes down the gate at the centre of the face, and the feeder to the machine is taken from it to the right or left, as required. The cables employed are armoured, but the armouring does not constitute the return. The machine is flitted, not made to cut back, the objection to the latter method being that the haulage-rope has to be carried over the motors and it is found inconvenient. The rate of advance is 50 lineal yards in a shift of about 8 hours.

The table given on the following page is taken from a valuable paper on coal-cutting machines by Mr. W. E. Garforth,[2] and furnishes details of the performance of Diamond coal-cutters in three different seams.

The Jeffrey Longwall Coal-cutting Machine.—This is an American machine of the disc type. It differs in one or two points from those already described, and will be seen in fig. 124. The parts of the machine are balanced (the motor balancing the wheel) so that it is possible to use only one rail, the side thrust being taken by sleepers held in position by screw-jacks fixed against the roof. The cutter-wheel may be tilted up or down by means of a hand-wheel, and by this means inequalities in the floor can be successfully cut over.

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[1] Particulars supplied by Mr. John Neal, jun.

[2] *Transactions Inst. Mining Engineers*, xxiii. 312.

The gearing is similar to that already described, but is enclosed in a casing so that it can run in oil—a great advantage where it can be applied, as it makes the machine much quieter in action. The machine is driven by one shunt-wound motor of 25 h.p. It is a question whether the shunt-wound machine is as suitable for this purpose as the series-wound, as it will not start against a heavy load, and consequently there might be a little trouble in starting the machine if stopped during a cut. The cutter has from 20 to 25 teeth, and makes 40 to 45 revolutions per minute. The

PERFORMANCE OF DIAMOND COAL-CUTTERS.

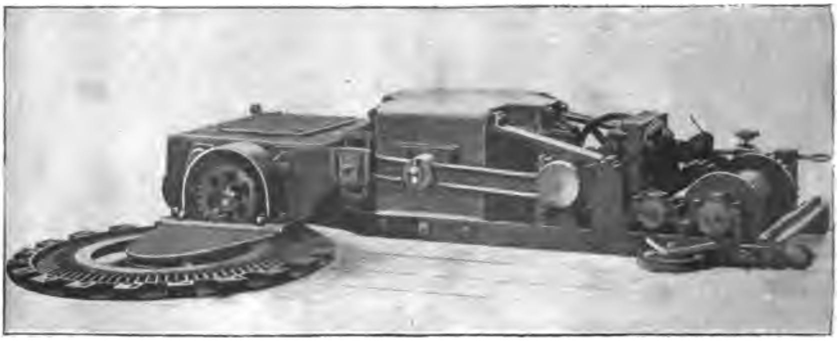
—	CASE A	CASE B	CASE C
Section of seam—			
Roof: Blue bind	—	—	—
Seam: Coal	2 ft. 10 in.	4 ft.	3 ft. 3 in.
Inferior coal and dirt	9 in.	15 in.	9 in.
Thill: Spavin	—	—	—
Depth below surface	390 ft.	960 ft.	1,500 ft.
Inclination of seam	1 in 16	Level	Level
Method of working	Longwall and packed gateways	End-on longwall and packed gateways	
Depth undercut by machine	5½ ft.	5½ ft.	5½ ft.
Thickness of cut	5½ in.	5 to 6 in.	5 to 6 in.
Average distance over one month cut by machine per eight-hours' shift	180 ft.	226½ ft.	129 ft.
Number of men employed with machine	3	3	3
Average weight over one month got per man per shift	170 cwt.	111¾ cwt.	130½ cwt.
Weight of coal in tubs	5 cwt.	8½ cwt.	8¼ cwt.
Average number of tubs filled per man per shift	34	13	16
Average wages over one month earned per shift: stallmen	10*s*. 5*d*.	9*s*. 10¼*d*.	10*s*. 9¼*d*.
Average wages over one month earned per shift: fillers	7*s*. 3*d*.	8*s*.	7*s*. 8*d*.
Conditions of work	Stallmen do timbering, filling, packing, making height, &c.		
Special men drive and clean up small coal and dirt after the machine	Paid datal wages		
Thickness of dirt taken up for packing	4 in.	15 in.	7 in.
Diameter of props	3½ in.	6 in.	5 in.
Width between props	4 ft.	4 ft.	4 ft.
Dimensions of chocks	Chocks are used where required	5 × 5 × 19 in.	6 × 6 × 15 in.
Width between chocks		24 ft.	24 ft.
Thickness of ripping	24 in.	36 in.	28 in.
Width of ripping	5 ft.	7 ft.	7 ft.
Getting price: hand-holing	1*s*. 11*d*.	1*s*. 9*d*.	—
,, machine-holing	1*s*.	1*s*.	11*d*.

haulage-drum is provided with a friction-clutch, which, in case of excessive strain, slips and eases the machine. The rate of advance is, of course, variable and can be varied from 8 inches to 24 inches per minute.

This machine is in use at a Yorkshire colliery, and was inspected by the writer a short time ago.

The seam is 180 yards from the surface, and about 3 feet thick. The coal-cutter is at present about two miles from the pit bottom, the voltage at the generator on the surface being 500, and about 450 at the motor. The amount of current taken by the machine is 30 to 40 ampères normally, but in cutting through 'brasses' and stone, which are met with frequently, the current goes up to 70 and 80 ampères. The cut is 5 feet 6 inches deep by 6 inches high. Three men are at the cutter, and one man goes in front of the cutter and behind the fillers, timbering and dressing the face down for the cutter. The average cut per shift is 40 yards, but the machine is actually running only about half the shift, the rest of the time being spent in timbering, laying rails, &c. The face is 500 yards long, and the cutter works three shifts, filling being done on two shifts. The gates are 22 yards apart, and there is one filler at each side of each gate. The handle used to tilt the wheel is constantly in use. The cables in the roads are mostly concentric with the return conductor uninsulated; but the cable in the face, which is dragged after the cutter, is a twin cable wound round with tar band.

FIG. 124.

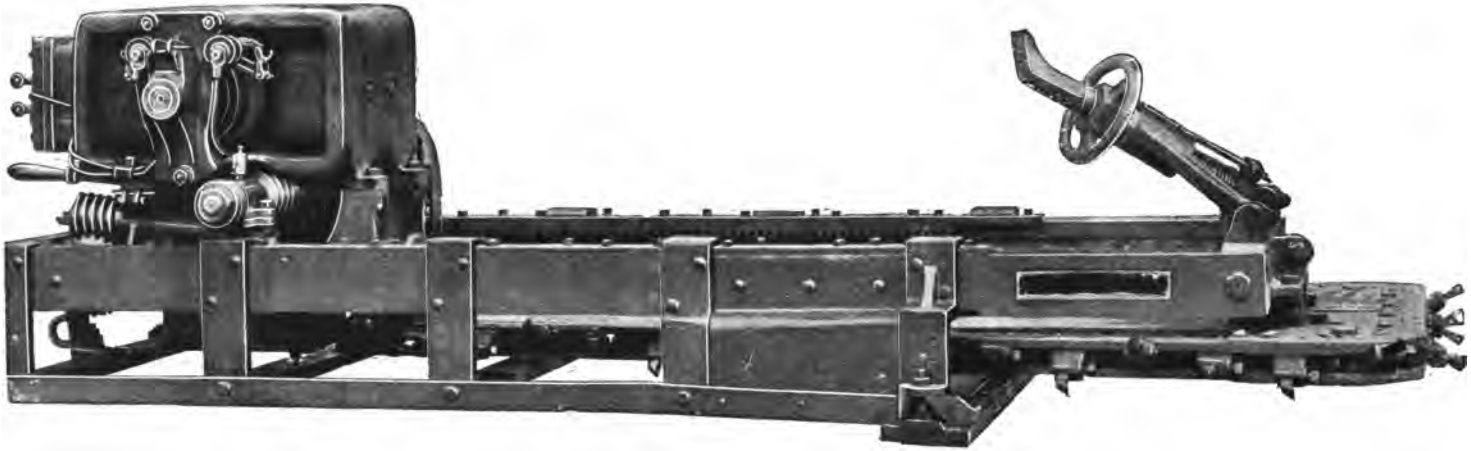


JEFFREY ELECTRIC LONGWALL MACHINE.

(4) **Chain Machines.**—This class of coal-cutter has found great favour in America, where disc machines are comparatively rare. It is only fair to say, however, that the first chain machines were designed in this country about thirty-five years ago.

Jeffrey Chain Coal-cutter.—This machine is designed specially for pillar and stall or 'room' working, and is used in this country for heading work. It consists (see fig. 125) of a stationary frame inside which slides the cutter-frame, to the rear end of which is attached the electric motor. The motor drives, by means of spur- and bevel-gearing, a sprocket-wheel

Fig. 125.



Jeffrey Electric Chain Heading Machine.

which works the chain, on to which straight teeth are fastened, the teeth being set like those of a saw. On the under side of the stationary frame will be seen a rack, and there is a similar rack on the other side; this is the feed-rack; the spur-wheels which engage in the rack are driven by means of the worm-gearing shown in the figure.

Screw-jacks are provided at both ends of the stationary frame. In starting a cut, the front and back jacks are screwed firmly against the face and roof; the motor is then switched on, and this causes the chain-cutter to revolve in its frame, and the teeth on the front end of the chain, being in contact with the face, cut into the coal; at the same time the feed-gear worked by the worms advances the motor and the frame in which the cutter-chain revolves into the coal, the cut thus getting deeper and deeper. At the end of the cut the motor is reversed and the sliding frame travels back along the stationary frame in readiness for the next cut. The machine is then moved laterally across the face, a distance equal to the width of the cut, and another cut is made, and so on

A trolley is provided on which the machine can be transported from place to place, and, if necessary, the electric motor can be made to work the trolley, thus dispensing with a horse. The electric motor is of 18 h.p., shunt wound, the average horse-power required being about 12. The machines are built to cut 5 feet, 6 feet, and 7 feet, the width of cut being 39 inches or 44 inches, and the depth of cut 4 inches. The length required in which to work the machine is about 6 feet longer than the distance under-cut, which of course makes its use in a long-wall face impracticable.

On a recent visit to the Stanton Colliery, Burton-on-Trent, this machine was seen at work driving a heading in the Stocking Seam which is 6 feet in thickness; only 4 feet 6 inches of coal is taken out in the heading, the rest being left as a roof. The machine took a cut of 39 inches in width to a depth of 5 feet 8 inches to 5 feet 10 inches. Owing to the floor lifting a little it was found better to make the cut in two operations—*i.e.*, to cut in half-way, then reverse and start again at the beginning and cut the remaining half. The height of cut was 4 inches. The width of heading was 9 feet, which necessitated three cuts. The first cut was made in about 6¾ minutes; 10 minutes were occupied in moving the machine ready for the second cut, which was made in 6½ minutes; 6 minutes were occupied in shifting the machine for the third cut, and 6½ minutes were spent in cutting. This makes a total of 35¾ minutes in under-cutting a place 9 feet wide to a depth of 5 feet 8 inches, or about 51 square feet, and it will be seen that this performance compares very favourably with that of any coal-cutting machine.

Mr. Robert Hay, the certificated manager, informed the writers that he had driven a length of 30 yards of coal-heading 9 feet wide in six days.

At the mines of the Youghiogheny Coal Company, Pennsylvania,[1] a large number of Jeffrey machines are in operation. The seam is worked on a modification of the pillar-and-stall system, with stalls 36 feet wide, separated by ribs of coal 6 feet wide. The long-wall system] cannot be adopted, as there is no material available with which to build packs. The following table is given by Mr. Gresley :—

Particulars of Results of Electric Coal-cutting Machines.

Type of Machine and Number in Use, 11 500-*volt Chain-cutter Breast Machines.*

Builders of machine, including motors	Jeffrey Manufacturing Company, Ohio.
Depth of cut made by machine	69 inches.
Width of cut made by machine	36 inches.
Height of cut made by machine	4 inches.
Weight of machine	2,800 lbs.
Horse-power of motor on machine	12
Area under-cut per run or cut	17 square feet.
Time occupied in making one cut	4·5 minutes.
Power consumed when cutting	15·4 h.p.
Power consumed when backing out	2·8 h.p.
Average number of cuts per shift	30.
Number of shifts of 9 hours per day	2.
Tons (2,000 lbs.) produced per shift per machine	60.
Time occupied cutting	About 3 hours.
Time occupied moving machine about, changing bits, &c.	About 6 hours.
Average number of cuts made in each 21-foot room	7.
Number of bits on a chain	45.
Weight cut per chain used up	35,000 tons (2,000 lbs.).
Production per man by machine per day	6 tons.
Production per man by pick work	4 tons.
Number of 21-foot rooms apportioned to each machine per double shift	24.
Number of men operating machine	2.
Fewer men employed where machines operate or increased production per miner by use of machines	33 per cent.
Less pit room occupied by machines	33 per cent.
Output per machine per year	28,000 tons (2,000 lbs.).
Cost of blasting and loading up machine-cut coal	One-half pick mining rate.
Cost of under-cutting by machines	One-eighth pick mining rate.
Approximate saving by machines, including renewals, interest, and depreciation	Per 2,000-lb. ton, 9 cents (= 4½*d.*).

In a recent paper in the 'Transactions of the Institute of Mining Engineers,'[2] a comparison is instituted between a disc machine and a chanibreast machine, and the writer of the paper comes to the conclusion that for their particular mine the chain-cutter has decided advantages. The mine is worked on the double-stall system, with stalls 60 feet wide and 30-foot ribs between the stalls. The roof is of hard sandstone rock, which allows of the necessary width in the face for the Jeffrey machine. The advantages claimed for the chain machine are that it requires about 30 per cent. less power, that it only makes half the noise, that it is impossible for it to climb up or down in the coal. There are very few mines, however, where it would be considered advisable to have a space of 12 feet between the face and the timbering, and this could not be accomplished at the mine in question were it not for the ribs of coal left.

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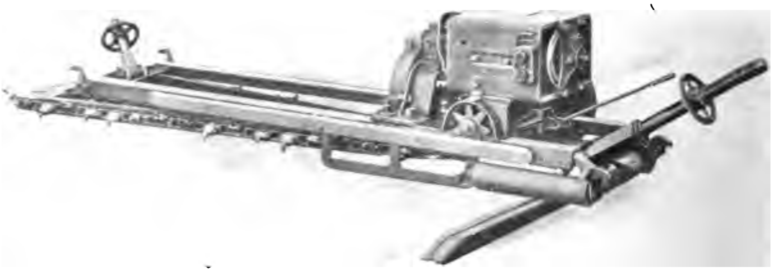
[1] 'Central Station Electric Coal-mining Plant in Pennsylvania, U.S.A.,' by W. S. Gresley ; *Proc. Inst. C.E.* Part I.

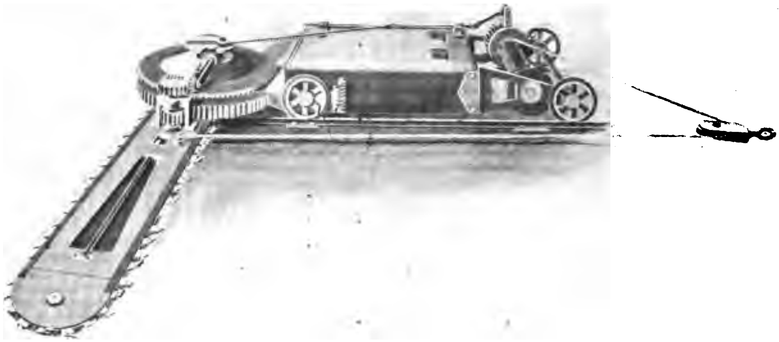
[2] 'Mechanical Under-cutting in Cape Colony,' by John Colley ; *Trans. Inst. Mining Engineers*, xxii. Part I.

FIG. 126.



GOODMAN ELECTRIC CHAIN HEADING MACHINE.

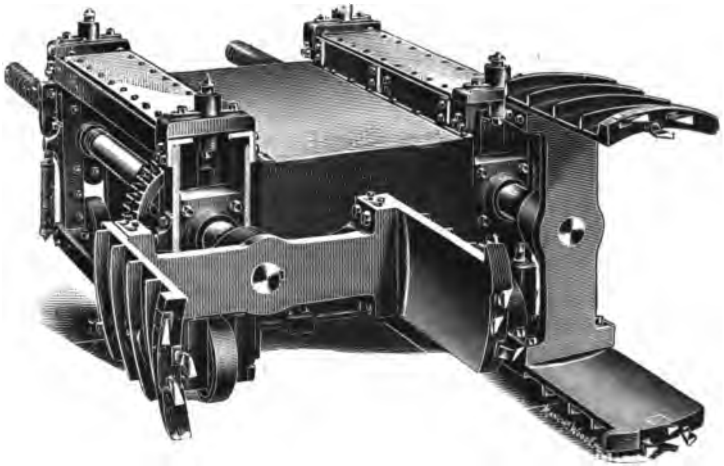
FIG. 127.



MORGAN-GARDNER ELECTRIC LONGWALL MACHINE.

Other Chain Machines.—A similar machine to the Jeffrey is the Goodman Electric Chain-breast Machine (see fig. 126). It differs from the Jeffrey in having rollers fixed at the rear end, which materially add to the speed with which the machine is shifted across the face. The stationary frame also is of different construction, the cutter-chain being supported entirely under the frame, thus enabling a cut to be taken directly at floor level. The motor winding is so compounded that it automatically adjusts its speed to the amount of work it has to do. It runs at a moderate speed with light cutting and slows down with heavy cutting or extremely dull bits.

FIG. 128.



STANLEY'S ELECTRIC HEADING MACHINE.

Another modification of the chain machine is to have a narrow chain working at right angles to the face (as shown in fig. 127) similar to the original form of Baird Coal-cutter, but, as far as the writers know, such machines have not been largely introduced.

Stanley's Coal-heading Machine.—This well-known heading machine can also be driven electrically. The double form is shown in fig. 128. This is a 4-foot by 8-foot machine, the dimensions over the frame and gearing being 6 feet 3 inches by 5 feet 10 inches by 3 feet. It is fitted with a 30 h.p. motor, and the total weight is about 5½ tons.

CHAPTER XI

TYPICAL ELECTRIC PLANTS RECENTLY ERECTED

Continuous-current Plant—Three-phase Plant—Continuous-current and Three-phase Side by Side.

THE first plant described, and illustrated diagrammatically in fig. 129, is a continuous-current plant recently erected under the supervision of one of the authors at a large Yorkshire colliery.[1] As will be seen from the detailed particulars given, the plant consists of two separate electric generators, each driven by a steam-turbine (De Laval). The power of each turbine generator is 100 kilowatts, or about 133 E.H.P., and the total h.p. is therefore 266 E.H.P., equivalent to, say, 300 I.H.P. in the steam-engine. The steam pressure as delivered to the turbines is about 100 lbs. per square inch. The exhaust steam from each turbine is condensed by means of a jet condenser. The condensation water is taken from the cold-water reservoir adjoining by means of a small centrifugal pump driven by a De Laval turbine, which raises the water to a height of about 7 feet above the steam-turbine. There is a separate condenser for each engine. A vacuum of 25 inches is obtained. The plant works with great steadiness and has given satisfaction. The full voltage of 275 is not at present always in use, as 250 volts is sufficient. The higher voltage will be used when the power is taken to greater distances from the generator.

Cables.—From generating station along overhead line and down shaft to ③ pump, 91/·095,[2] insulated with vulcanised indiarubber, taped and braided ; carried by leather suspenders from ⅛-inch straining wire, stretched on insulators from pole to pole ; fixed to headgear in clamps similar to those used for guide-ropes ; carried down shaft in wooden casing carried on buntons 6 feet apart, as shown in fig. 130. The cables are laid in the 1½-inch grooves, and cemented in with bitumastic solution. From ③ pump along level to top of incline, 19/14 ; down incline ; 19/14 ; along level to haulage ④, 7/14 ; down dip to pump ⑤, 7/16 ; down shaft to pumps ⑥ and ⑦, 91/·095 ; down engine-plane to ⑧, ⑨, and ⑩, 37/13 ; along level to ⑪ and ⑫, 7/18.

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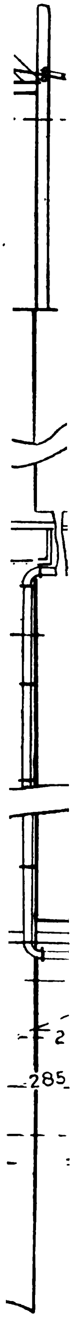
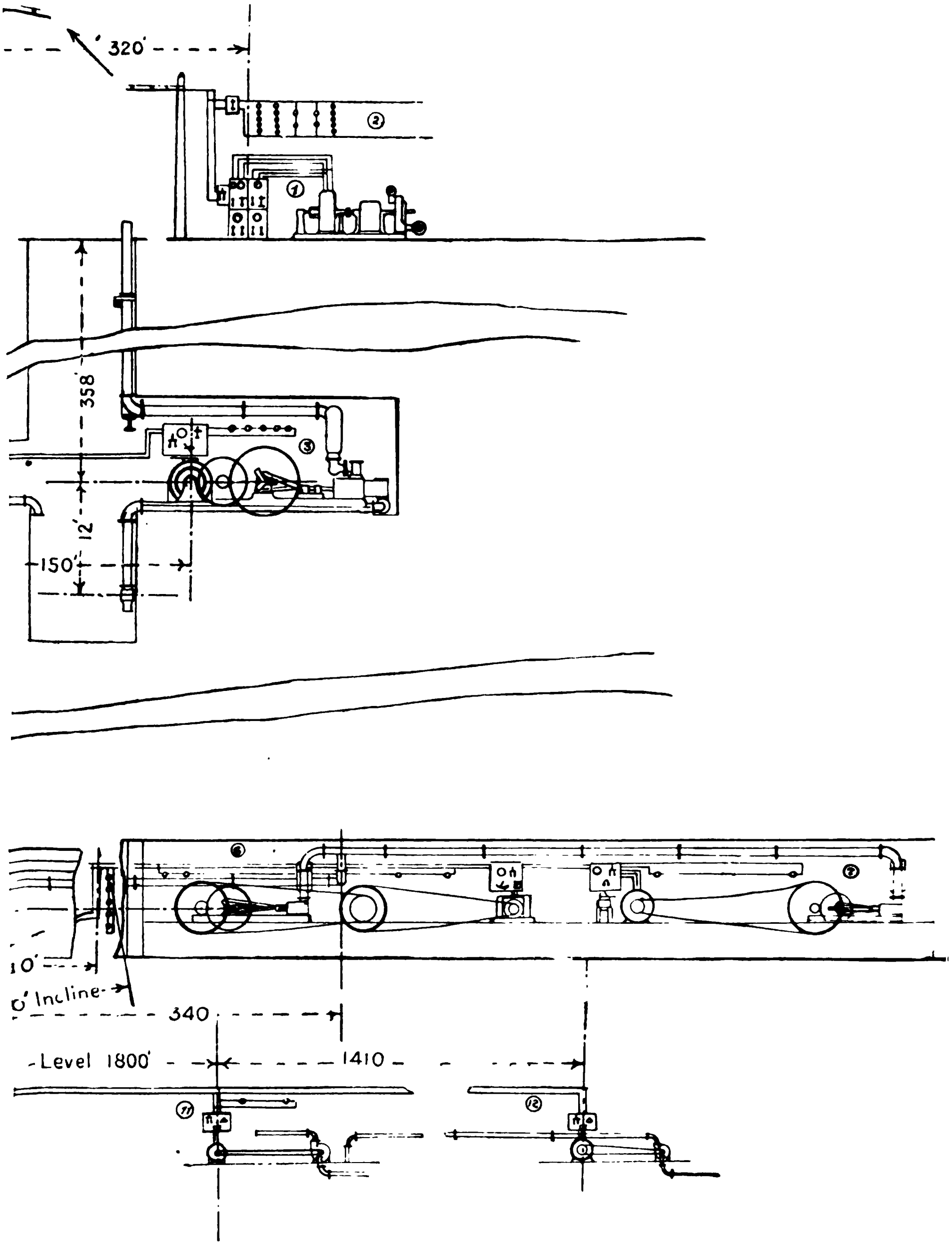
[1] Since this description was written another turbine and electric generator have been added, and the waste gases from the coke ovens have been used to generate steam.

[2] 91/·095 = 91 wires, each ·095 inch diameter.



AT A



Yorkshire Colliery.

① Generating Station.—Plant: Two steam-turbines (De Laval), 150 h.p. each, geared to two double generators (Greenwood & Batley), compound wound, two armatures being connected in series, each giving 275 volts and 180 ampères; speed of generators, 1,085 revolutions per minute. Switchboard: Apparatus for running two turbine sets in parallel—two ammeters, one voltmeter, two automatic maximum-current cut-outs, two equaliser switches, four single-pole switches, two field rheostats, one two-pole feeder switch; lightning arrester.

② Eighty 16 candle-power lamps on surface.

③ Pumping Station.—Plant: Three-throw 12″ × 18″ single-acting pump (Stephenson)—head 358′, suction 12′, 27 revolutions per minute; 122 h.p. shunt-wound open motor (Brit. Thomson-Houston Co.), 500 revolutions, geared to pump. Switchboard: One ammeter, one overload cut-out, one two-pole switch, one starting switch and rheostat.

④ Hauling-engine House.—Plant: 3′ 6″ main rope hauling drum (Heenan & Froude) and gearing; 35 h.p. compound-wound motor (Wilson Hartnell), driving by belt; starting and reversing controller with five diverter resistances (Brit. Thomson-Houston Co.). Switchboard: One ammeter, one double-pole switch and fuses, one automatic cut-out.

⑤ Dip Pump.—One three-throw 4″ × 6″ single-acting pump (Scott & Mountain); 5½ h.p. shunt-wound motor (Brit. Thomson-Houston Co.), 700 revolutions per minute; head 80′; 1,950′ of 2½″ delivery pipe. Switchboard: One ammeter, one double-pole switch and field discharge resistance,[1] one starting-switch and rheostat with automatic zero- and maximum-current release.

⑥ Pumping Station.—7″ × 12″ three-throw pump (Warner), rope-driven—head 280′; 25 h.p. Crompton motor, shunt-wound, 550 revolutions per minute. Switchboard: One ammeter, one two-pole switch and fuses, one starting switch and rheostat.

⑦ Spare Pump to ⑥.—8″ × 12″ three-throw pump (Stephenson), belt-driven; 35 h.p. shunt-wound motor (Wilson Hartnell), 800 revolutions. Switchboard: One ammeter, one two-pole switch, one automatic circuit-breaker, one starting switch.

⑧ Hauling Engine.—Main and tail hauling drums, 5′ diameter, and gearing and clutches (Sandycroft Foundry Co., near Chester); 50 h.p. shunt-wound motor (Brit. Thomson-Houston Co.), 900 revolutions. Switchboard: One ammeter, one overload release, one two-pole switch, one starting switch and rheostat.

⑨ Pumping Station.—6″ × 12″ three-throw pump (Stephenson)—head 320′, 2,850′ of 5″ delivery pipe; 35 h.p. shunt-wound motor(Wilson Hartnell), 800 revolutions; liquid starting-switch. Switchboard: One ammeter, one two-pole switch, one automatic circuit-breaker.

⑩ Spare Pump to ⑨.—6″ × 9″ three-throw pump (Scott & Mountain); 25 h.p. shunt-wound motor (Scott & Mountain); starting-switch. Switchboard: One ammeter, one voltmeter, one two-pole switch, one automatic circuit-breaker.

⑪ Centrifugal Pump.—4″ Invincible pump (Gwynne), belt-driven; 7 h.p. shunt-wound motor (Scott & Mountain), 1,350 revolutions. Switchboard: One two-pole switch, one starting switch with automatic maximum- and zero-current release, one field discharge resistance—head nil, 4″ delivery pipe, discharging into suction of ⑨.

⑫ Centrifugal Pump.—3½″ Invincible pump; 5½ h.p. shunt-wound motor (Brit. Thomson-Houston Co.), 750 revolutions. Switchboard: As ⑪; head, 15′, and 1,410′ of 3½″ delivery-pipe.

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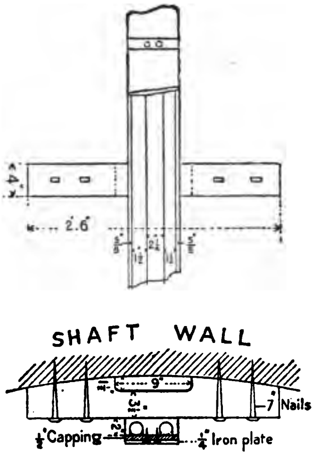
[1] The 'field discharge resistance' is a resistance connected across the terminals of the shunt coils to take the self-inductive discharge produced on breaking the shunt circuit.

To face page 198

Cables down the pit are kept, where possible, at opposite sides of the road. Where the roof and sides are strong they are fastened to props or bars by wooden cleats screwed on to the timber. Where the roof is not so good they are hung by tar-band from the bars, and a little slack left between adjacent points of support. All cables have vulcanised insulation, taped and braided.

FIG. 130.



METHOD OF CARRYING CABLES DOWN SHAFT.

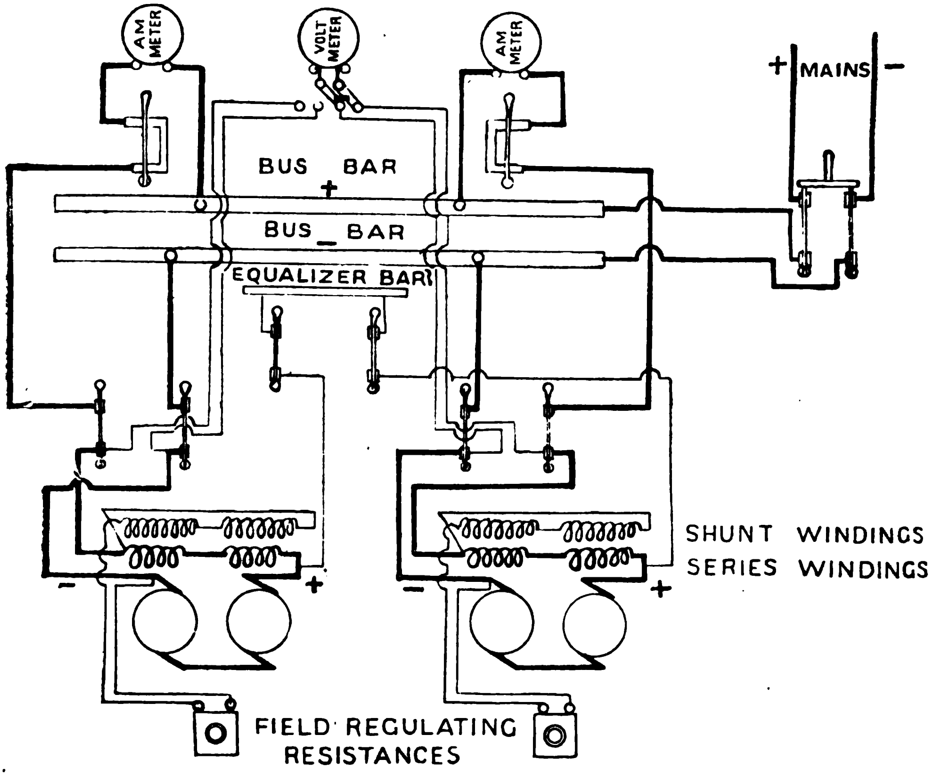
Currents taken.—

			Ampères
②	Eighty lamps on surface		9
③	Three-throw pump	about	135
④	Single-rope haulage	,,	25
⑤	Three-throw pump	,,	6
⑥	Three-throw pump	,,	40
⑦	Three-throw pump (duplicate)	,,	(40)
⑧	Main and tail haulage	,,	65
⑨	Three-throw pump	,,	40
⑩	Three-throw pump (duplicate)	,,	(40)
⑪	Centrifugal pump	,,	6
⑫	Centrifugal pump	,,	6
	Thirty-six lights underground	=	4
	Total current liable to be on at once (not including duplicate pumps)		336

Further plant in course of erection will utilise the whole of the power of the two generating sets.

Switchboard.—Fig. 131 shows the connection of the switchboard, &c., in the generating station. The thick lines represent the cables along which the main currents pass, and the thin lines the shunt, voltmeter, and equaliser wires. Starting from the positive brush of one generator, the current passes through the series windings, the main switch, the automatic overload cut-out, the ammeter, and so to the positive bus-bar. Starting from the same point in the opposite direction, the current passes through the armature to the negative brush, to the positive brush of the other armature, through this armature to the negative brush, the main switch and the negative bus-bar.

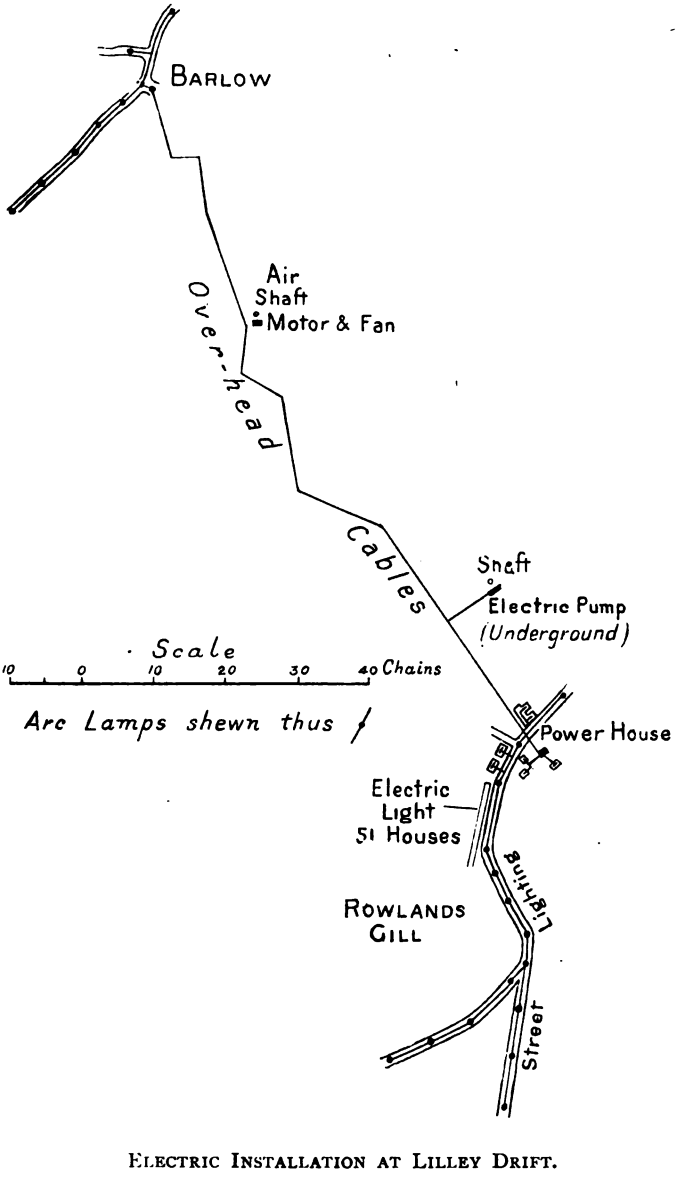
Fig. 131.



Switchboard of Electric Installation at a Yorkshire Colliery.

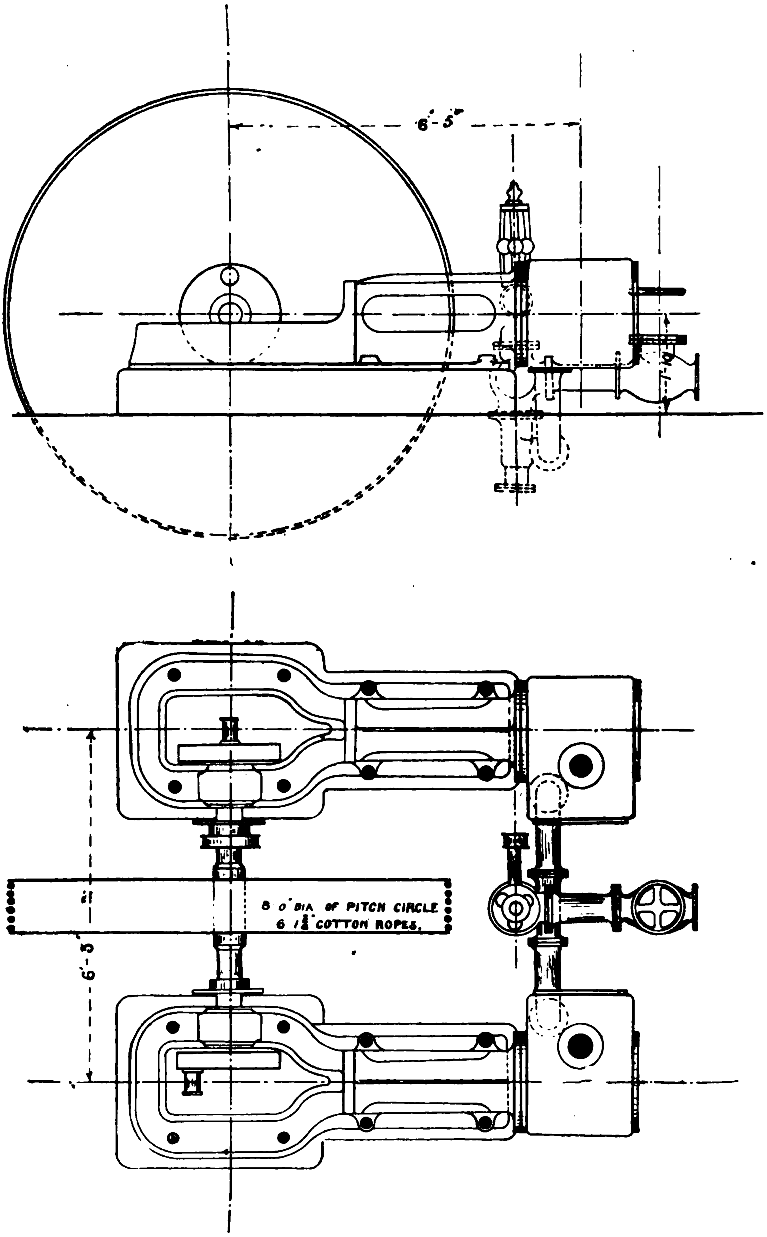
The voltmeter is connected through a two-way switch across the terminals of either machine. The middle wire (or equaliser) starts from the positive brush, through the equaliser switch, to the equaliser bar.

FIG. 132.



ELECTRIC INSTALLATION AT LILLEY DRIFT.

FIG. 133.

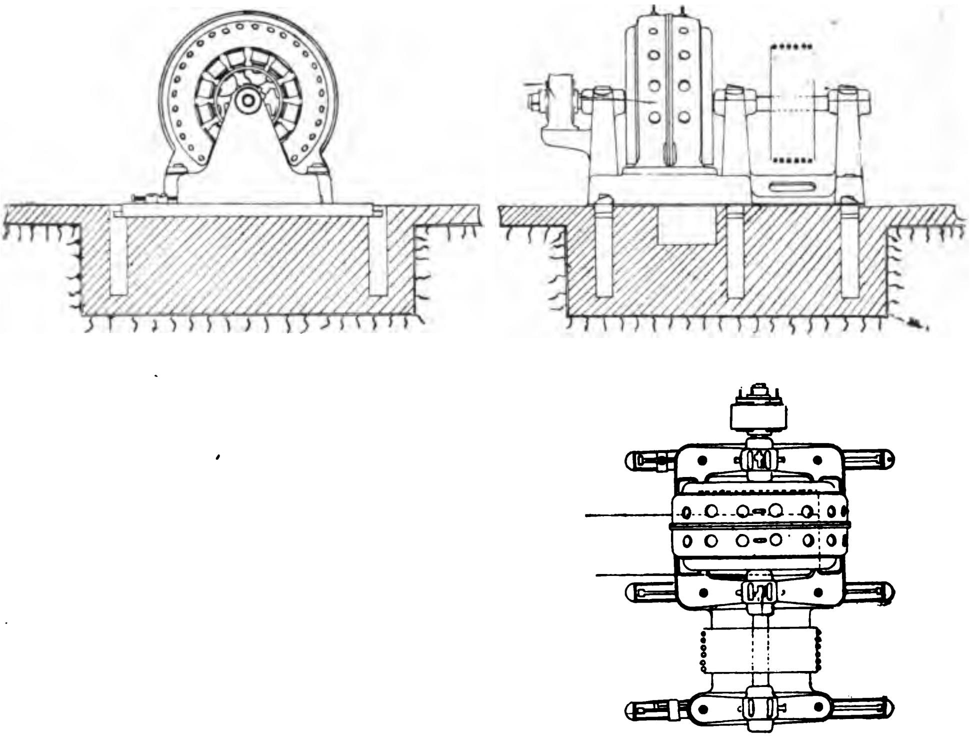


LILLEY DRIFT INSTALLATION: ENGINES.

The shunt-fields are connected from outside the series-winding, through the regulating resistance, to the negative terminal. These regulating resistances must be adjusted until both machines give exactly the same voltage, so that the readings of the two ammeters are identical, showing that each machine is taking its proper share of the load.

The feeding mains are connected to the bus-bars through the main feeder switch.

FIG. 134.



LILLEY DRIFT INSTALLATION: ELECTRIC GENERATOR.

Other Switches.—One double-pole switch in generating station for surface lighting; two single-pole switches at junction near pump ③, for cutting off ④ and ⑤; four single-pole switches at junction of engine plane and level for cutting off ④ and ⑤; four single-pole switches near pump ⑥ for cutting off ⑥ and ⑦, and also ⑧, ⑨, ⑩, ⑪, and ⑫.

Three-phase Plant.—The following is a description of a plant recently erected by the Corlett Electrical Engineering Company, Limited at Lilley Drift, Rowland's Gill, belonging to the owners of the Priestman's Collieries, Limited, Newcastle-on-Tyne. A sketch plan of the installation is shown in fig. 132.

Engines.—Pair of horizontal high-pressure engines (see fig. 133), having cylinders 16½ inches diameter by 16 inches stroke, and running at about 150 revolutions per minute; steam pressure, 45 lbs. Engines fitted with rope pulley between the engines 8 feet diameter, grooved for six ropes 1⅜ inch diameter. Engines fitted with high-speed governor and suitable lubricators to all journals.

Generator.—Of the alternate-current three-phase type (see fig. 134), with stationary armature and revolving fields. The armature windings, carried in suitable tunnels through the laminated cores, insulated with micanite tubes. The field windings consist of twelve poles, all wound and carried on centre casting, securely keyed to main shaft, with suitable collecting rings for conveying exciting current to the fields. Bearings three in number, of the self-oiling ring type; rope-pulley, 37 inches diameter: speed of generator, 400 revolutions; tension, 550 volts; output, 140 h.p.

Exciter.—A four-pole continuous-current shunt-wound machine, bolted to main shaft of generator and running at same speed as generator.

Main Switchboard.—The switchboard shown in fig. 135 is built up of wrought steel framework and suitable number of marble panels.

Generator Panel, fitted with voltmeter and ammeter; main three-pole switch and fuse; multiple-contact field rheostat.

Feeder Panels, arranged for two circuits, each circuit being fitted with ammeter, main three-pole switch and fuse—No. 1 of 60 h.p. for fan circuit; No. 2 of 25 h.p. for extensions. Also with three similar two-pole circuits for the primary sides of the transformers.

The low-tension distribution comprises one similar panel arranged for a suitable number of circuits for controlling the various sections of lighting.

All the high-pressure switches are arranged at the back of the board, the handles only projecting through the face, so that there is no possibility of shock to the attendant. The fuses are of the detachable type, the fuse-carrier consisting of a massive porcelain block, and so arranged that it can be removed and a new fuse fitted without danger.

The low-tension distribution panel for the lighting is fitted with switches and fuses mounted on the face of the board.

There are at present two static transformers fitted behind the main switchboard for reducing the tension from 550 to 250 volts, each 10 kilowatts capacity.

Transmission Line to the Fan Station.—This line is about one mile long, and is carried as nearly as possible in a straight line from the power house to the fan station. The poles are extra-stout creosoted poles, fitted with specially strong oak arms and special high-quality porcelain insulators. Six bare wires, each No. 2 S.W.G., carry the current.

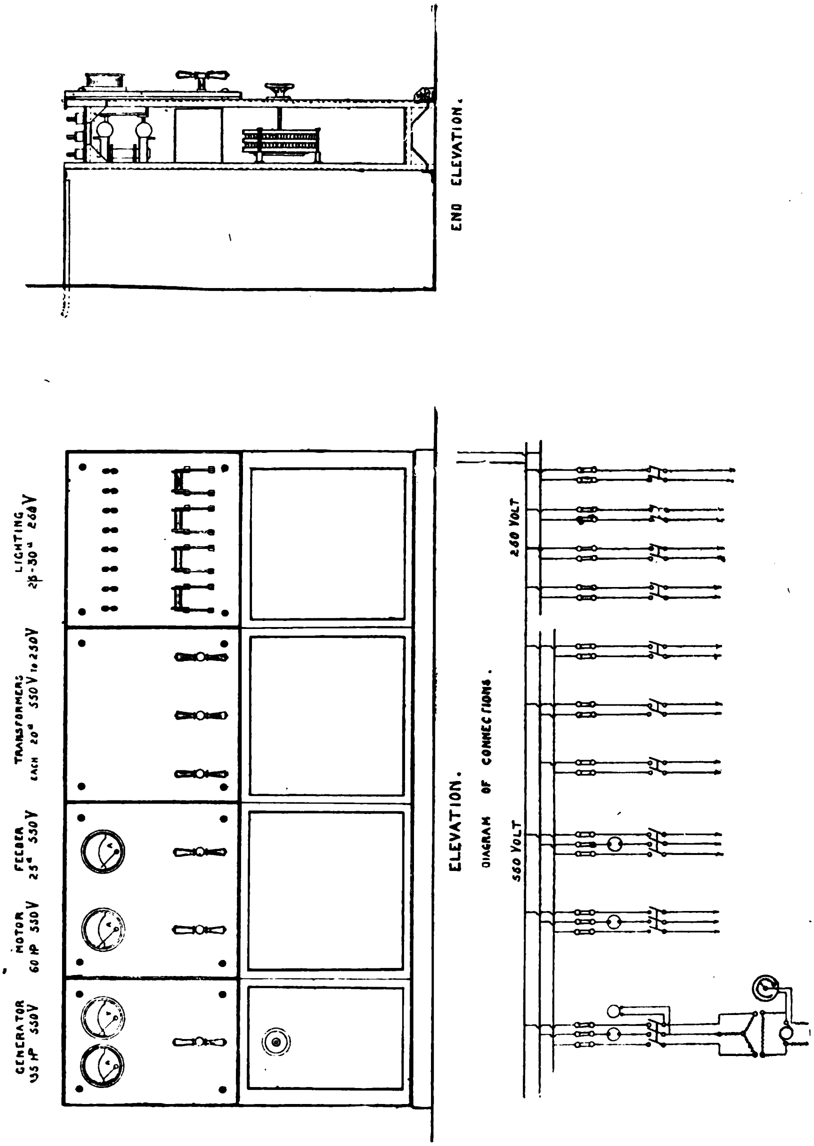


FIG. 135.

LILLEY DRIFT INSTALLATION: SWITCHBOARD.

Fan.—The fan is of the Capell double-inlet type, 7 feet diameter by 8 feet wide, and is designed for an output of 140,000 cubic feet of air at

1½-inch water-gauge, and running at 275 revolutions. The fan is fitted with four bearings, also of the self-oiling ring type. The arrangement of the fan house is shown in fig. 136.

Motor.—The motor is a standard pattern three-phase alternate-current motor, rated output 60 B.H.P. at 600 revolutions, and of the non-synchronous type. It is fitted with three brass slip-rings and with clutch gear, so that when the motor has attained its normal speed, by throwing over the handle the slip-rings are short-circuited and the brushes raised, so that the moving part of the motor is only in contact with its two bearings. The power from the motor is transmitted to the fan through a double orange tan endless belt. As all bearings of both fan and motor are of the self-oiling ring type, and as there are no brushes or contacts in use on the motor, the amount of attention required by the plant is small, and it is in practice found quite safe to arrange for periodical visits and not to keep a permanent attendant.

Electric Pump.—There is also in the mine a self-contained electric pump of the three-throw type, having rams 4 inches diameter by 6 inches stroke, and running at 450 revolutions per minute. This is driven by a 5 h.p. motor, the whole mounted on one bedplate and driven by means of raw-hide gear.

Lighting.—The whole of the colliery machinery in the vicinity of the power-house is supplied with incandescent lighting, and also the workshops and offices. Further, the residences of the various officials are lighted, and, in addition, the schools, chapel, and about fifty workmen's cottages.

Besides the private lighting above mentioned, the streets of the village of Rowlands Gill, extending for about one mile from the power-house, are also supplied with incandescent lamps, the wires being carried in a similar way to the main transmission line.

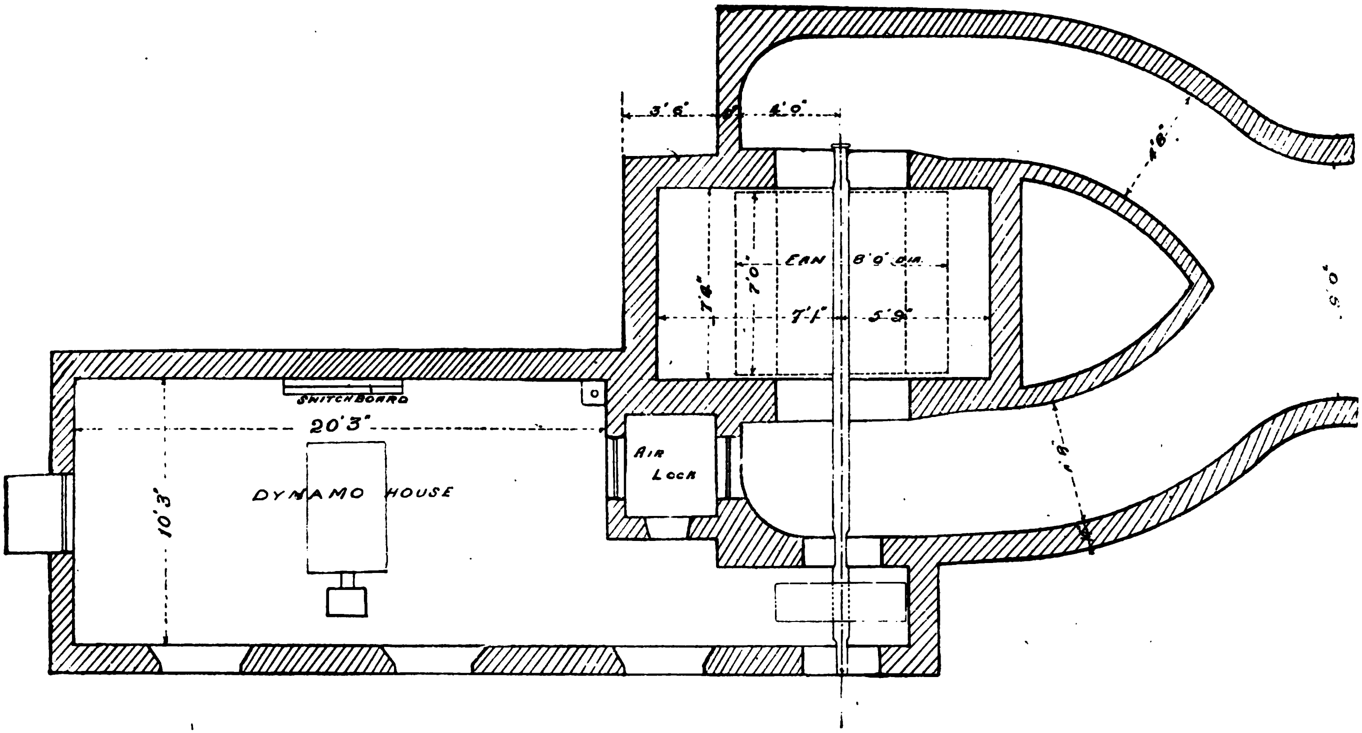
The village of Barlow, which is situated about half a mile beyond the fan station, at a distance of about one and a half mile from the power-house, is also being fitted with electric lighting in the streets, the power being taken from the main fan line, and, as there is no constant attendant in the fan station, the lighting of this village will be controlled by an automatic electric time switch, which will switch the lights on and off at predetermined hours.

The whole of the plant, which has now been working for some months without giving the slightest trouble, was erected by the Corlett Electrical Engineering Company, Limited.

Combined Continuous-current and Three-phase Plant.—The following is a description of a plant erected under the supervision of one of the authors at a large Derbyshire colliery.

The first plant to be erected was of the continuous-current type, intended for electric lighting. A pair of tandem compound horizontal

Fig. 136.



Lilley Drift Installation : Fan-house.

engines; two high-pressure cylinders, diameter 11 inches; two low-pressure cylinders, diameter 20½ inches, stroke 2 feet 10 inches, driving-belt wheel 12 feet diameter, with leather belt 2 feet wide; countershaft with belt-wheel 3 feet diameter for main belt; belt-wheels on the countershaft 7 feet diameter, driving two Hartnell shunt-wound two-pole generators, on which the belt-wheels are 14 inches diameter. The average speed of the lighting engines is 50 revolutions per minute. The driving-pulleys on the countershaft are loose on the shaft, but can be thrown into work by a brush-and-comb gear.[1] This gear has given satisfactory results, and it can be thrown in and out at full speed. The dynamos are each capable of producing 95 ampères at 230 volts and 970 revolutions a minute, and they have worked very satisfactorily. There is also a Crompton dynamo, 230 volts, 100 ampères, 860 revolutions, 15-inch pulley, two-pole, shunt-wound. The electric cable is taken on poles to the workshops, where arc lights of the enclosed type are used, and also glow lamps. All the engine-rooms, pit-bank screens, sidings, offices, and the pit-bottom are lighted by this plant. The current is also taken to the village, a distance of about half a mile, and used for lighting dwelling-houses, shops, and hotel. The cables are arranged on the two-wire system.

Three-phase Hauling Plant.—For the underground haulage, which may eventually be extended to a considerable distance, a new plant has been recently erected, consisting of a pair of horizontal tandem compound engines, two high-pressure cylinders, 10 inches diameter; two low-pressure cylinders, 16 inches diameter, steam-pressure in engine-room about 90 lbs., stroke 2 feet 8 inches, driving-wheel 12 feet, driving on to wheel of countershaft 3 feet 6 inches diameter; dynamo driving-wheel on countershaft 5 feet diameter, pulley on dynamo 2 feet 1 inch diameter. The average number of revolutions of the engine is 96 per minute. Three-phase Westinghouse ten-pole generator, 136 ampères per phase, 450 volts, 720 revolutions and 60 periods. The power in watts $= 136 \times \sqrt{3} \times 450 \times$ (power factor $= \cdot 93$) $= 98{,}600$, and the E.H.P. $= 98{,}600 \div 746 = 132$. The current is taken in one three-core cable down the pit, which is suspended in the shaft inside an iron pipe to protect it from injury. It is taken to the engine-room near the pit bottom, where it is connected to a Westinghouse motor, 420 volts, 580 revolutions and 60 periods, 136 ampères per phase, watts $= 136 \times \sqrt{3} \times 420 \times$ (power factor $= \cdot 93$) $= 91{,}986 = 126$ E.H.P. On the motor shaft is a belt-wheel, 2 feet diameter, driving on to a pulley-wheel 9 feet 6 inches diameter. A pinion on this shaft, 27 inches diameter, gears into a spur wheel on the countershaft 97 inches diameter, the pinion on which shaft, 19 inches diameter, gears into a spur wheel on the drum shaft, 83 inches diameter. The drum is 6 feet diameter, and takes four and a half turns of a ¾-inch rope. The plant works efficiently and gives satisfaction.

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[1] Makers, Cowlishaw, Walker & Co., Etruria, Staffordshire.

CHAPTER XII

ELECTRIC LIGHTING BY ARC AND GLOW LAMPS

Arc Lamps—Electric Glow or Incandescent Lamps.

We will now consider briefly the relative advantages and disadvantages of electric lighting by means of both arc and incandescent lamps and their suitability for mining work.

Arc Lamps.—These consist of cylindrical carbon rods, about $\frac{1}{2}$ inch diameter in the majority of cases, attached to a mechanism controlled by electro-magnets through which the current flows. If the carbon ends touch one another and the current is switched on, the electro-magnets, then energised, cause the mechanism to separate the carbon rods by a short air-gap, which may be anything up to $\frac{3}{8}$ inch long. In the act of doing this a spark is caused which volatilises some of the carbon, forming a conducting path for the current to flow across in the short air-gap between the ends. The current then intensely heats the carbon vapour and tips, so that they emit a powerful light.

At least 40 volts must be maintained at the carbon tips in order to keep the arc glowing, and in practice about 50 volts is allowed at the terminals of the lamp, if of the *open* or '*inverted*' type. There is, however, another type of arc lamps very widely used at the present day, called the '*enclosed*' form, in which the carbons, or rather the arc and part of the carbons, are *enclosed* in a glass globe arranged so that there is practically no circulation of air. Consequently, in this type combustion of carbon goes on very slowly, and carbons that would last only about twenty hours in the open types will last about 200 hours in the enclosed type. The length of arc in the latter reaches to $\frac{3}{8}$ inch, against about $\frac{1}{8}$ inch in the former, thus allowing more of the light to get out. The efficiency of an arc lamp is usually reckoned in watts per candle-power, though this should be termed its inefficiency. Ordinary arc lamps require from 0·5 to 0·8 watt per candle, and it is usual to allow 1 I.H.P. at the engine of an electric generating set for each lamp of 1,000 candle-power (c.p.) roughly.

Comparing the open and enclosed types, the advantages lie mostly with the latter, and are as follows:—

(1) Much smaller consumption of carbon.

(2) Will burn for much longer periods.

(3) Require re-trimming much less frequently.

(4) Require smaller currents (roughly, one-half).

(5) Will burn on higher voltage circuits (100 to 200 volts).

(6) Immunity from fire, as the arc, being enclosed in a tight-fitting chamber, cannot set fire to anything through dropping sparks or fragments of red-hot carbon.

The initial cost of open and enclosed arc lamps is about the same, but when we consider the *running cost* after first installation, the difference is very evident; for instance, compare a 50-volt 10-ampère arc of the open type, burning twenty hours, with a 100-volt 5-ampère one enclosed, burning 150 hours without a renewal of carbons. In the latter the cost of carbon and labour of re-trimming are each only about $\frac{20}{150}$, or $\frac{1}{7}$ of that in the open type, but the luminosity is less (from 10 to 30 per cent.). The smaller current required entails smaller cables, and therefore less cost in these at the outset. Arc lamps of all types are much more successful with direct than alternating current, and with this latter take roughly 25 per cent. more electrical energy for the same amount of light than with direct currents, while the distribution of light, so far as open spaces is concerned, is much inferior. In the direct-current arc particles of carbon are carried from the upper or $+^{ve}$ carbon to the lower or $-^{ve}$ one, and in the upper carbon a crater or hollow is formed at the end, which tends to concentrate the light and throw it down to the ground; with alternating currents both carbons burn away equally, the light passing outward in all directions, and the maximum rays horizontally.

Electric Glow or Incandescent Lamps.—These consist of a specially manufactured carbon thread, or filament, enclosed in a small glass bulb from which nearly all the air has been removed. When the current passes through this filament it heats it to intense or white heat, causing the light now so universally known.

The efficiency, or watts per candle emitted, varies from 2½ to 5½, and the life from 600 to 1,400 hours, without the lamp becoming too dull to use.

Glow lamps are made nowadays in enormous numbers for any voltage, from 2 up to 250 volts, and of almost any c.p., from 1 up to 2,000, the higher c.p. lamps being more efficient.

The higher voltage lamps, such as 200, last a shorter time than the lower voltage ones, such as those for 100 volts. A good average is to allow 3½ watts per candle for lamps of or about 100 volts and 4½ watts for 200-volt lamps, each of c.p. up to about 50. It is usual to allow eleven 16-c.p.

60-watt glow lamps per I.H.P. at the engine of a generating set. Comparing the lighting, by arc and glow lamps, of mines or other places, we see that, roughly speaking, 1 I.H.P. will produce about 160 c.p. with glow lamps, and about 1,000 c.p. with arc lamps. For large open spaces, lighting by direct-current enclosed arc lamps is more economical both in first cost and running cost afterwards, and should therefore be adopted where practicable.

One single circuit can then be made to do for both arc and glow lamps—namely, that shown in fig. 63, of either one 100-volt arc lamp in parallel with 100-volt glow lamps on 100-volt mains, or two 100-volt arcs in series across 200-volt mains with 200-volt glow lamps.

It is, however, preferable to have at least two arc lamps in series, as one tends then to steady the other. Such an arrangement or combination might in cases prove more economical than separate arc and glow lamp circuits, notwithstanding the 200-volt glow lamp being less efficient than the 100-volt one.

In offices and rooms it is preferable to use glow lamps, but they cannot compete with arc lamps for large open spaces. The height of the posts on which they are fixed and the distance apart must be governed by the brilliancy of the illumination required.

For a detailed description of the construction of electric glow and arc lamps, see Maycock's 'Electric Wiring, Fittings, Switches, and Lamps.'

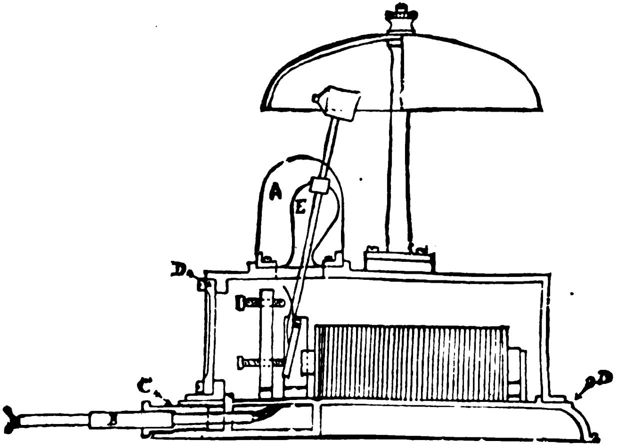
CHAPTER XIII

MISCELLANEOUS APPLICATIONS OF ELECTRICITY

Telephones—Signal Bells—Electric Blasting—Electric Safety Lamps—Lighting Safety Lamps by Electricity—Electric Drills—Electric Welding—Electric Winding.

Telephones.—The principle on which the telephone works is so well known as to require little or no description in these pages; suffice it to say that the vibrations of a very thin, soft iron disc, caused by the human voice speaking at it, are electrically transmitted along a wire and exactly reproduced at the other end on a similar iron disc actuated by an electro-magnet, itself controlled by the intermittent currents generated electro-magnetically by the voice at the sending end. The line connecting the two places may be suspended overhead or laid underground, and may consist of iron, copper, or phosphor-bronze wire, of comparatively small

FIG. 137.

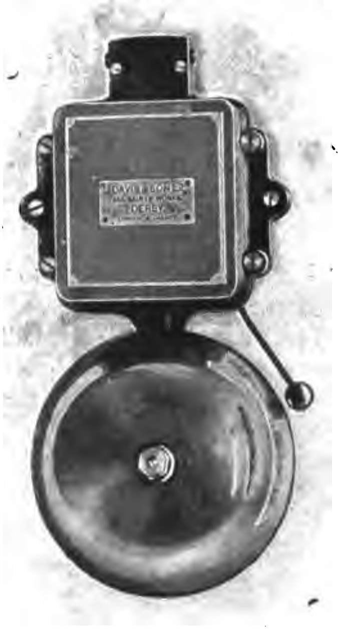


DAMP-, DUST-, AND GAS-PROOF MINING BELL.

gauge, as the current used in the telephone itself is extremely small. Up to comparatively recently, it has been the common practice to have a separate outward wire for each telephone and return by the earth for them all. Now, however, metallic wires are being used and the earth not used so much for a return, as this arrangement entails less interference in the telephone, while at the same time it reduces the resistance of the circuit, which is an advantage.

Sometimes, however, at mines, the ordinary signal-bell circuits are used temporarily for telephone circuits, to save having separate ones for the latter. This cannot be recommended, since it is possible for the bells and telephone to interfere with each other and cause complication.

FIG. 138.



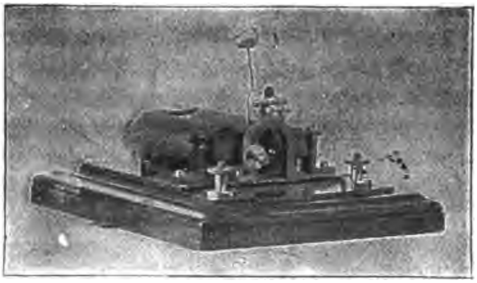
ELECTRIC BELL. HANGING FORM.

Telephones are of great use in mining work, and should be installed in a systematic manner all over the *workings*. Should a mishap then occur at any point, assistance could be at once telephoned for and the nature of the mishap quickly explained to the proper persons.

Signal Bells.—These are electric bells, usually of the 'single-stroke' type, though sometimes of the 'trembling' form, which are employed to call the attention of someone, perhaps in the engine-house, to listen at the telephone, or in the case of winding, hauling, &c., as a signal to *start*, *stop*, &c., according to a prearranged code of signal rings.

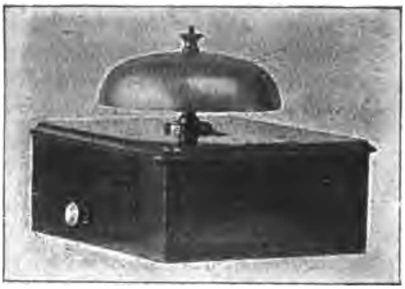
For mining purposes electric bells should be *damp-*, *dust-*, and *gas-proof*, and one form having these qualifications is shown in side elevation, fig. 137. It is made by Messrs. Davis & Sons, Limited, of Derby, and consists of two small electro-magnets side by side, which act on a soft iron plate armature, pivoted on a short horizontal spindle. A rod fixed to the upper edge of this armature terminates in a knob for striking the inside of the gong. The play of the armature is limited by two adjustable set screws working in an upright standard. All the working parts are enclosed in a nearly dust-proof metal case, D, and the two insulated wires, B, are led in through a stuffing-box or gland, C, in the case.

FIG. 139.



SINGLE-STROKE BELL. COVER REMOVED.

FIG. 140.



SINGLE-STROKE BELL. OUTSIDE VIEW.

Fig. 138 shows the hanging form, and figs. 139 and 140 the views of a table form with ringing push-key combined.

It is not necessary for a single-stroke bell to be gas-tight, as the circuit at the bell is never broken. A trembling bell, however, must be, as the contact lever carrying the armature makes and breaks the circuit many times a minute, creating a little spark each time. In such cases the containing box must be strong enough to withstand the explosion of the small amount of gas contained in it without fracture or contact with the outside gas.

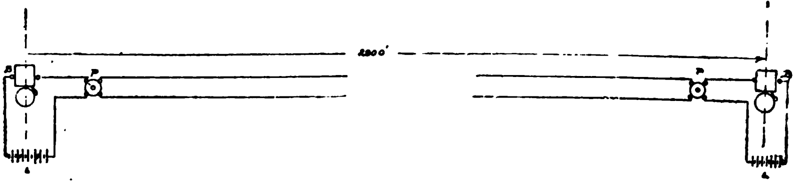
If the same line be used for both signal bells and telephones, there is the liability for a telephone call to be mistaken at the engine-room for a signal, with possibly the starting or stopping of the engine at a moment when it was not wanted. This might even entail loss of life.

Separate circuits are, therefore, to be recommended for both telephones and signal bells, and, as the size of wire required for each is small, the initial cost may and probably will be much more than outweighed by greater ease and facilities in working afterwards.

Both sets could be carried together either underground or overhead, thus entailing only one expense in laying them down. Tolerably well insulated copper for both kinds of circuits would be the best to use, (except haulage signal wires, which are usually bare in the haulage road, to enable signals to be made instantly at any point), the gauge depending on the distance run. For a house-bell circuit a single copper wire, $\frac{1}{22}$ to $\frac{1}{18}$ gauge would be used. For outside work and long distances, $\frac{1}{18}$ to $\frac{1}{14}$ gauge; the latter size could serve for a bell two miles distant. Telephone wire need not be any bigger.

Electric Signals.—Fig. 141 shows the arrangement of an electric signalling apparatus for a main and tail haulage road. Both bells, B, can be rung from either end of the line by depressing the push, P, which makes a connection between the two line wires. The bells are Mercier's patent, with 7-inch gongs, and it is found that a battery of seven Leclanché cells, connected up in series at each end, is powerful enough to ring them through 2,900 feet of line.

FIG. 141.

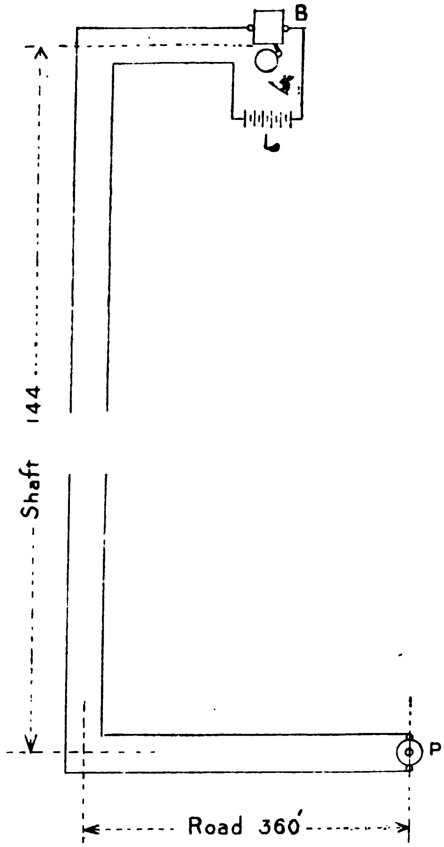


ELECTRIC SIGNALS ON HAULAGE ROAD.

B, Bell. P, Push. L, Battery of seven Leclanché Cells.

The line wire is of iron, No. 10½ B.W.G., and is supported on earthenware insulators, to which it is attached by fine wire ; the insulators, which are 2⅛ inches in diameter, with a groove ¼ inch deep and 1¼ inch thick, are screwed on to props or bars, and the two line wires kept about 8 inches apart, which is a convenient distance for making contact between the two, with a lamp or metal tool of any kind, when it is necessary to signal from some point on the road. It is found convenient to do the wiring at both ends with insulated wire—say, No. 16 B.W.G.

FIG. 142.



ELECTRIC SIGNAL ALONG ROAD AND UP SHAFT.

B, Bell. P, Push. L, Battery of six Leclanché Cells.

Fig. 142 shows a signalling arrangement for a haulage rope where the engine is situated on the surface ; in this case there is no down signal. The wires in the shaft, 48 yards deep, are No. 16 B.W.G., and are indiarubber covered, taped, and braided, and supported by two insulators fixed to the brickwork at the top of the shaft and attached to two more insulators at the bottom of the shaft. The wires in the underground road are No. 10½ bare iron wire, supported as in the case previously described. The bell is an Edwards, with a 5-inch gong, and six Leclanché cells in series are found to be powerful enough to ring it. In both cases trembling bells are used, not single-stroke bells.

Electric Blasting.—The use of electricity as a means of firing shots, although first practised in this country about the year 1840, is a comparatively recent innovation in the mining of coal and other minerals. In the Coal-mines Regulation Act of 1887 no restriction was placed upon the method of firing the shots, while in Rule 12 (section *d*) a reference is made to the use of the pricker, which was employed when firing a shot with a squib or 'German.' About this time, however, considerable attention was being paid to the question of coal-dust in mines, and the necessity of having a safer explosive than gunpowder for fiery and dusty mines was recognised by the passing of an 'Act to amend the Coal-mines Regulation Act' in 1896, which gave the Secretary of State power to prohibit the use of any explosive deemed likely to be dangerous. Following upon this came several orders regulating the use of explosives in coal-mines, in which it is provided that in all coal-mines not naturally wet throughout, 'every charge shall be fired by an efficient electrical apparatus, or by some other means equally secure against the ignition of inflammable gas or coal-dust.' The use of electricity for firing shots, however, had become very common in mines some time before the issue of these orders.

Advantages of Electric Shot Firing.—The advantages of this method of firing shots may be summarised briefly as follows :—

1. The person firing the shot can do so from a distance, and thus the risk of a premature explosion is avoided.

2. There is very little danger of a shot hanging fire ; with a tape fuse any dampness or a defect in the fuse might cause it to smoulder and delay the explosion, with the possibility of injuring fatally or otherwise the shot-firer, who had returned to the place under the impression that a 'miss shot' had occurred. The hanging fire of an electric fuse is extremely rare.

3. A saving of time in the case of a 'miss shot.' It is provided in the special rules that no person shall return to the place until after a certain stated interval of time has elapsed, but very frequently there is a provision enabling this to be dispensed with in case the attempt to fire the shot has been made with some electrical appliance.

4. No burning fuse being employed, there is nothing (apart from the detonator and explosive) to fire gas in the working place.

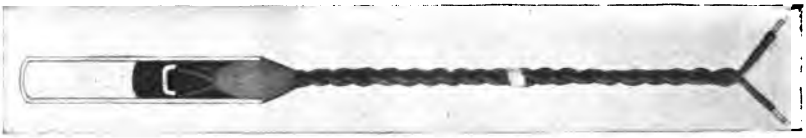
5. If necessary, any number of shots may be fired simultaneously.

With regard to the first-named of these advantages, it is of special importance when considering the firing of shots in shaft sinking. With the ordinary tape fuse, sufficient length is provided to enable the sinkers to be withdrawn before the shots explode; but any mishap in connection with the winding apparatus might involve very serious consequences. With electric blasting the exploder is at the pit top, and the shots are not fired until everyone is out of the pit.

There are three methods of electric shot firing in use:—

1. With low-tension fuse and exploder.
2. With high-tension fuse and exploder.
3. With high- or low-tension fuse and the necessary electric current derived from the lighting or power mains.

FIG. 143.

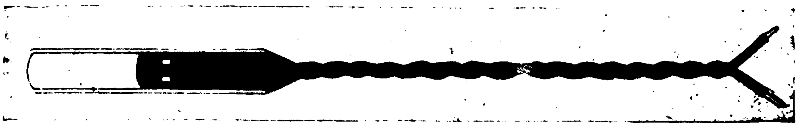


LOW-TENSION ELECTRIC DETONATOR.

Low-tension System.—A low-tension fuse is shown in fig. 143, and consists of two tinned copper wires ·022 inch in diameter, the length depending on the depth of the hole; these wires are wrapped with cotton saturated with insulating compound, and for wet situations (such as shaft-sinking) are covered, in addition, with guttapercha or indiarubber.

The fuse wires terminate in the detonator, and are joined together by a bridge of fine platinum wire, which is embedded in a flashing mixture adjoining the detonating compound. The passage of the electric current heats the platinum wire to redness, the flashing mixture is ignited, and the detonator explodes.

FIG. 144.



HIGH-TENSION ELECTRIC DETONATOR.

High-tension System.—A high-tension fuse is shown in fig. 144, and differs from the low-tension fuse in only one respect—namely, the absence of the platinum wire bridge. A current of much higher voltage is used, and the explosion is caused either by a spark passing between the terminals and so igniting the sensitive chemical compound by which they are surrounded, or else by the heat generated owing to the resistance of this compound.

Exploders.—1. Primary batteries. Low-tension fuses, which only require a low voltage, may be fired by a primary battery. This may consist of a Leclanché cell (see figs. 9 and 10); the ordinary open-topped glass jar being replaced by an ebonite cell, the top of which is sealed so that loss by evaporation or spilling is avoided.

Dry batteries (see fig. 14) are more commonly used, however, and are preferred for mining work owing to their greater portability. The E.M.F. of a Leclanché cell or of a dry battery is nominally 1·55 volt.

The cell should have as low an internal resistance as possible. Mr. William Maurice, in a very valuable paper on the subject contributed to the Institution of Mining Engineers, gives the following interesting example on this particular point:[1]—

'Suppose, for example, treating the question in an off-hand manner, a dry cell, say, 2½ inches in diameter and 7 inches in length, with an internal resistance of 0·7 ohm, be selected to fire Nobel low-tension fuses through a 90-foot twin wire of No. 20 S.W.G. It can be seen almost at a glance that the apparatus is foredoomed to failure, for the total resistance of the circuit (resistance of cell + resistance of line + resistance of fuse) exceeds 3 ohms, and since about 0·6 ampère current is required to fully incandesce a fuse bridge, it follows by Ohm's Law (E.M.F. = current × resistance) that the E.M.F. of the cell (1·55) is barely sufficient to overcome the resistance of the circuit. If, on the other hand, a cell of lower internal resistance, say, a C-size Obach (with an internal resistance of 0·25 ohm) be selected together with a firing line containing more copper, say, a 3/22 S.W.G., this apparently trifling modification makes all the difference between failure and success.'

The total resistance in the latter example is as follows:—

	Ohm
Rc. (internal resistance of cell)	0·25
Rl. (resistance of 180 feet 3/22 S.W.G.) . .	0·79
Rf. (resistance of fuse bridge)	0·75
Total resistance	1·79

On taking the product of 1·79 × 0·6 (fusing current), it is found that the E.M.F. required to force that current through the circuit is less than the E.M.F. available at the terminals of the battery; hence this set may be expected to perform its work in an efficient manner.

2. Magneto-exploders are very commonly used for firing both high-

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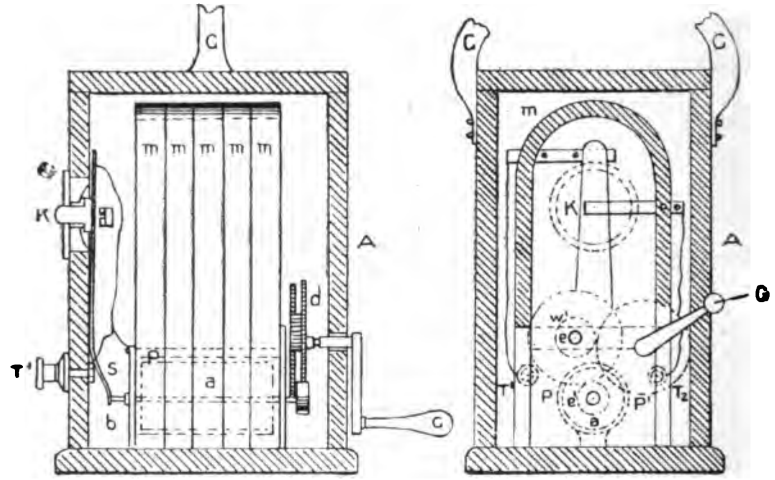
[1] *Transactions of the Institution of Mining Engineers*, xvi. 169.

and low-tension fuses. They depend upon the principle that when an armature is revolved between the poles of a permanent magnet an electric current is produced. A diagrammatic view of a magneto machine is shown in fig. 145.[1]

When a shot is to be fired the fuse wires are attached to the terminals, T^1 T^2, the handle, G, connected by gearing to the armature, *a*, is revolved, and when a good speed has been attained the button, K, is pressed in and the circuit through the fuse is completed.

The winding of the armature decides whether the fuse shall be high or low tension; in the former the armature is wound with a greater number of turns of finer wire. In course of time the magnets lose some of their strength and require to be re-magnetised.

FIG. 145.



MAGNETO-EXPLODER.

m m, Magnets. *a*, Armature. T^1 T^2, Terminals. K, Firing key. G, Handle.

3. Dynamo-electric exploders have the same principle as the ordinary continuous-current dynamo (see page 42). The electric current generated by revolving the armature is carried round the field magnets, converting them into electro-magnets and producing a much stronger magnetic field.

The 'Rackbar' exploder is constructed on this principle, but, instead of the armature being revolved by turning a handle, the teeth on the rackbar engage with those of a pinion on the armature shaft, and by forcing the rackbar rapidly down a high speed of the armature is attained. At the moment when the current is at its maximum strength (*i.e.*, when the rackbar is nearing the end of its stroke) the current is directed into the fuse wires by an automatic switch.[1]

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[1] Reproduced from a drawing in Mr. Wm. Maurice's paper.

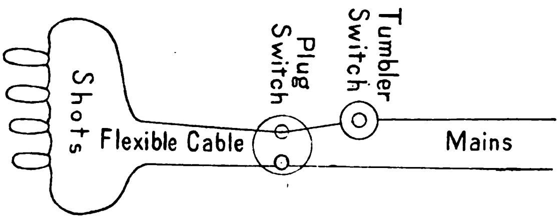
Dynamo-electric exploders are the most powerful, and are largely employed in shaft work and in large drifts. They possess the advantage of durability.

The dynamo or battery used in sinking must be locked up, and then it cannot be connected to the mains, except by the foreman after all the sinkers have left the shaft.

Testing Exploders.—A voltmeter or electric lamp may be used to test the power of either a dry battery or other exploder.

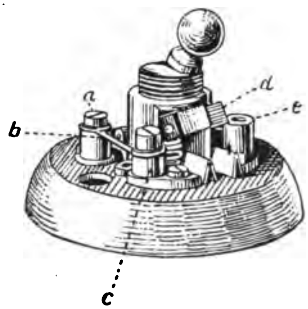
Firing from Lighting or Power Mains.—In the case of shaft-sinking or driving a stone drift, shot-firing can be effected by using the current from the lighting or power circuits about the mine where such exist. Special precautions must be taken to prevent accidental firing of shots—this being more likely to occur when using current derived from this source than when using an exploder.

FIG. 146.



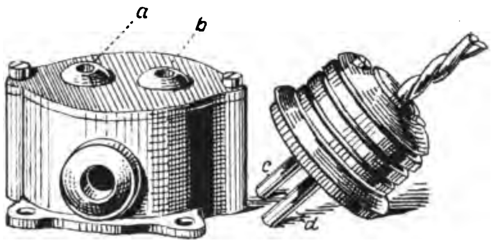
METHOD OF FIRING SHOTS FROM LIGHTING OR POWER MAINS.

FIG. 147.



TUMBLER SWITCH.

FIG. 148.



DOUBLE-POLE PLUG SWITCH.

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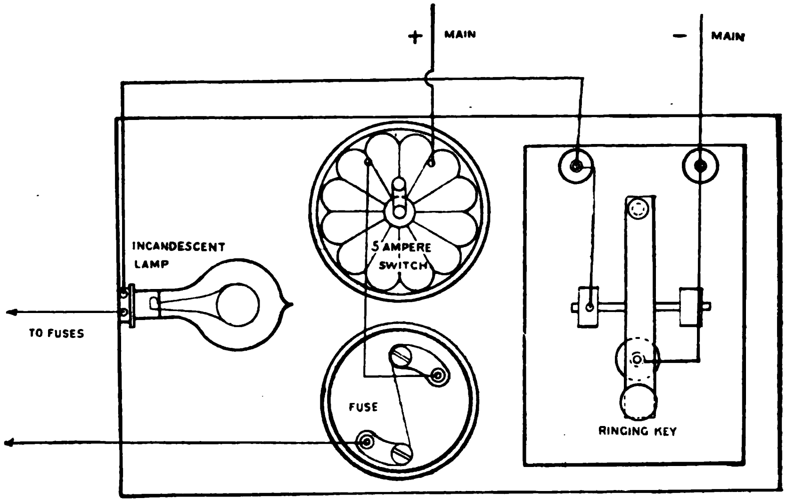
[1] For details of this and other exploders the reader is referred to Mr. W. Maurice's paper in *Transactions of the Institution of Mining Engineers*, xiv., xv., and xvi.

A double-pole switch, which makes contact with both mains, is employed, and this should be in a locked box under the sole control of one man. The shot-firer should be in a position to tell whether the mains are alive or not. This can be done by having an incandescent lamp or series of lamps joined across the mains before the double-pole switch is reached.

A sketch showing the necessary connections is shown in fig. 146. In this case a tumbler switch (see fig. 147) is inserted in one of the mains, and in addition there is a double-pole plug switch (see fig. 148). High- or low-tension fuses may be employed, and these are generally arranged in series if low tension, and in parallel if high tension.

Fig. 149 shows a shot-firing arrangement manufactured by Messrs. John Davis & Sons for use in firing from the mains in the case of either lighting or power circuits. It will be seen that there is a switch in each main, one being a tumbler switch and the other a press-down switch. There is also an incandescent lamp, by means of which the apparatus can be tested; by placing a piece of metal across the fuse terminals and switching on the positive main, and then depressing the key in the negative main, the lamp should light up if the apparatus is in working order. The whole is contained in a strong lock-up case, so that it cannot be tampered with.

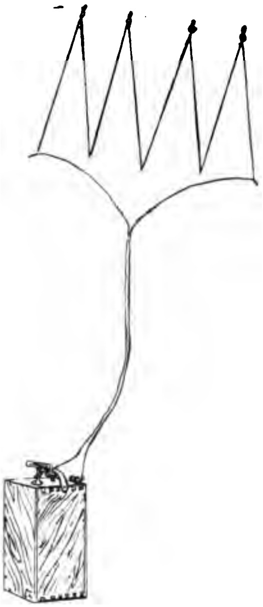
FIG. 149.



MESSRS. JOHN DAVIS & SONS' SHOT-FIRING KEY.

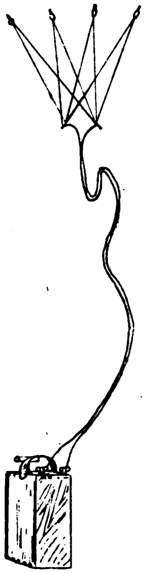
Arrangement of Wires for Simultaneous Blasting.—Where more than one shot has to be fired electrically there are two possible methods of connecting the various fuses to the exploder—namely, 'series' and 'parallel.' In the 'series' method, shown in fig. 150, the current passes from one firing main through all the fuses in turn and so back to the other firing main. As the resistance varies directly as the length, it will be seen that with the 'series' arrangement the total resistance is the sum of the resistance of each fuse added to the resistance of the line conductors or cables, and the amount of current required is not increased in proportion to the number of shots fired simultaneously, but the voltage rises in proportion to the number.

FIG. 150.



METHOD OF ARRANGING FUSES IN SERIES.

FIG. 151.



METHOD OF ARRANGING FUSES IN PARALLEL.

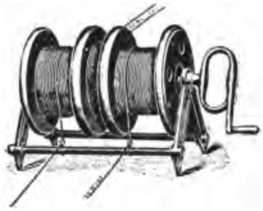
In the parallel method each fuse is connected directly to both mains, so that the current divides amongst the various fuses (see fig. 151). In this system the resistance of twenty fuses is less than that of a single fuse; the sectional area of the main conductors or cables must be in proportion to the current required—that is to say, in proportion to the number of fuses to be fired simultaneously.

Low-tension fuses which have a very low resistance are commonly arranged in 'series,' while high-tension fuses are arranged in 'parallel' if the number is too great to enable them to be fired in 'series.'

The 'series' arrangement is more convenient in practical work than the 'parallel' arrangement, especially in shaft-sinking, where it permits a ring of side shots to be easily arranged round a shaft without interfering with the work carried on in the sump, whereas with the 'parallel' method there will be more care and more wire required to avoid taking some of the wires across the shaft.

High or Low Tension.—For firing one shot or two shots with low-tension fuses a very light and cheap form of dry battery may be used, and this allows the operator to have one hand at liberty, with which he can pull back the firing cable as soon as he hears the report, and so save it from damage by falling rock or coal. Low-tension fuses can also, if desired, be tested by passing through them a weak current (insufficient to fire) and noting if the needle of a galvanometer in the circuit is moved. The manufacture has, however, got to such a pitch of excellence that the testing is perhaps unnecessary. For shaft work, however, where the length of the firing-line may be very long, the high-tension system permits of a thinner wire being used, and so it tends to reduce the cost of the firing-line.

FIG. 152.



CABLE REEL.

A reel employed to carry the firing cables for use in shaft and other work is shown in fig. 152.

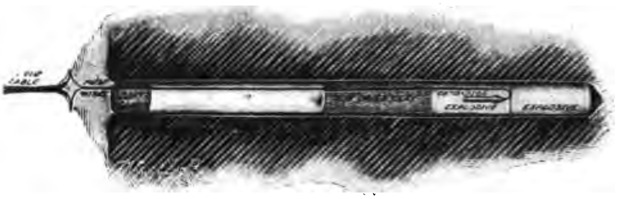
Miscellaneous Points.—An important factor for successful electric blasting is to see that the firing-line from the exploder to the fuse is not short-circuited—*i.e.*, that the two wires carrying the current shall be perfectly insulated from each other. In wet ground it is advisable to insulate the connection of the line-firing cable to the fuse wire by wrapping it with rubber tape or other insulating material.

With regard to the arrangement of the fuse wires in the shot-hole, Messrs. Nobel recommend the use of a fuse protector, which is simply an iron tube in which the fuse wires are placed whilst stemming.

To avoid striking the detonator during stemming Messrs. Nobel recommend that the detonator be placed at the back of the primer cartridge as shown in fig. 153.

Electric Shot-firing in Sinking Pit.—Fig. 154 shows a small series-wound dynamo used for this purpose and capable of giving a pressure of 500 volts. Current is generated in the armature, A, and passes from the brush, B_1 (working on a two-part commutator), through the windings, W, and thence to the contact, C, and to the terminal, T_2. From the brush, B_2, the current goes straight to the terminal, T_1. The armature is made to revolve by means of the arrangement shown in the figure. When the handle, H, is drawn up, the rider, R, rotates the spindle, S, which rotates the ratchet wheel, R W, without turning the wheel, G_1. On the down stroke, however, the ratchet wheel engages the pawls which are fixed to the gear wheel, G_1, which rotates the armature through G_2. The ratio of G_1 to G_2 is about two and a half to one, and the spindle, S, rotates about twice in the stroke, so that in the fraction of a second which it takes to push down the handle, the armature makes five revolutions. On reaching the bottom, R pushes down the contact, C, and the terminals, T_1 and T_2, are connected to the brushes; the armature now continues to rotate as long as its momentum lasts, the ratchet allowing it to do so, and a current is sent round the cables.

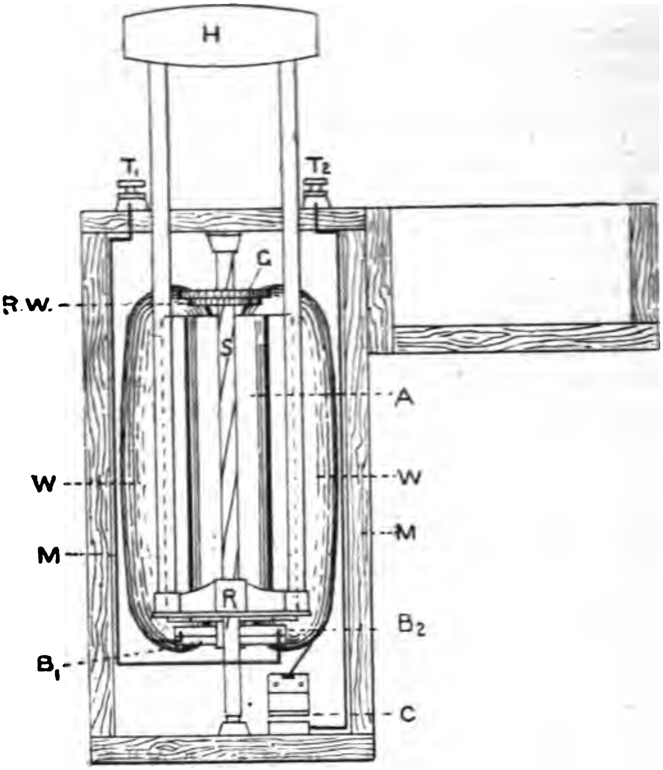
FIG. 153.



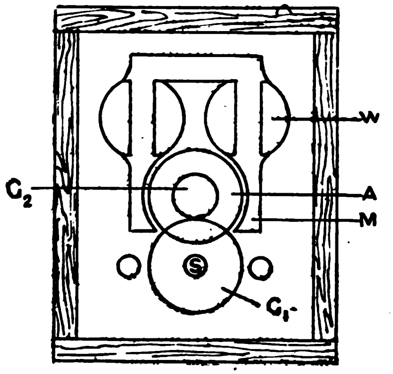
NOBEL'S ARRANGEMENT OF DETONATOR AND EXPLOSIVE.

The cable is a No. 16 copper wire, indiarubber covered, taped, and braided. A pair of these wires are wound on a wooden reel mounted on a trestle with a handle for winding and unwinding; they are let down the shaft when a shot is to be fired, and one is attached to each of two detonator wires on adjacent shots; the remaining detonators are connected up in series —*i.e.*, so that the current passes through them all in series. The battery box is kept locked while the connections are being made, and the chargeman down the pit has the key. The detonators used with this arrangement are No. 7 low-tension fuses and ignite a charge of 1½ to 2 lbs. of gelignite. The detonators are buried in a small cartridge of the explosive used, and this cartridge and the wires of the detonator are tied on to sticks; these are put down the holes after the rest of the charge is in, the top of the hole is plugged up with clay, and the wires connected up. In firing 'sumpers,' as shown in fig. 155, there are seven detonators connected in series. After the 'sumpers' have been fired and the loose rock sent out of the pit, eleven side holes (shown dotted in the

Fig. 154.



Elevation
Side of box removed

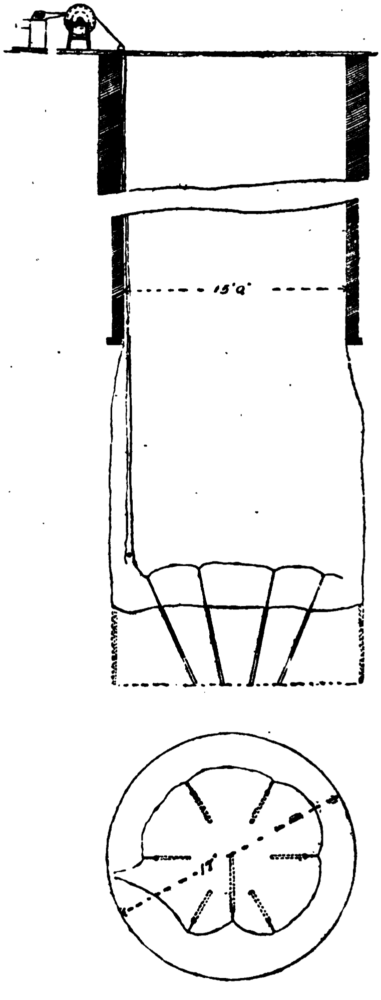


SECTIONAL PLAN.

Dynamo Electric Exploder.

elevation) are fired, and these are connected up in exactly the same way, eleven detonators in series. These particulars are for a 15-foot shaft, inside the brickwork, or 17 feet excavated, in average coal-measure shales and

Fig. 155.



Shot-firing in Sinking Pit.

sandstones The holes are drilled about 6 feet deep, and deepen the shaft about 5 feet 6 inches. With hoppits holding about 2 tons each, the sumpers and side holes together give from 50 to 55 hoppits full. The sumpers take four or five hours to drill, and the side holes five or six in ordinary measures, though in strong rock they may take three times as long. The dirt will be cleared out in about eight hours with a dozen men in the pit. Thus, if there are no delays the pit should advance, in soft ground, 5 feet 6 inches in eighteen to twenty hours, allowing one hour for charging, firing, and examining the sides after firing, which comes to about 7 feet per diem.

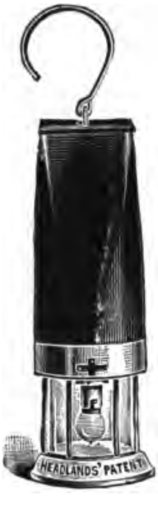
Electric Safety-lamps.

The use of the electric lamp in the working places of a mine has, up to the present, not had a very extensive application.

The importance of having a good light cannot be over-estimated, and a better light would no doubt decrease the number of accidents by falls [1] of roof and sides, and would be beneficial to the eyesight of those employed; but these advantages must not be obtained at the sacrifice of other principles of safety which are found in the ordinary oil safety-lamp.

The disadvantage of an electric lamp for mining work is that it will not detect the presence of poisonous or inflammable gases, consequently it can never in its present form be universally employed. At most collieries blasting operations are carried on, and it is essential that the state of the air in the mine should be known to the workmen. The question also arises as to whether the electric filament of the lamp is capable of igniting an explosive mixture of fire-damp and air; while the bulb remains intact, of course the lamp is perfectly safe, but in the event of it getting broken there is a possibility of such a mixture being fired.[2] It should be borne in mind, however, that the ordinary oil lamp, with its exposed glass, stands an equal or even greater chance of getting broken, in which case the flame would undoubtedly fire gas.

FIG. 156.



HEADLAND ELECTRIC LAMP.

The great difficulty found in designing an electric hand-lamp was to procure a sufficiently powerful, and at the same time portable, form of battery. The principal forms of electric lamps are the Headland lamp, Sussman lamp, and Bristol lamp.

The Headland Lamp.—This lamp, which is shown in fig. 156, uses the Headland battery already described on page 24. The lamp is made in two forms, one with a reflector behind and the other without, and it is the latter type which is illustrated in fig. 156. The photometric value of the two types is given in the table on pages 230 and 231.

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[1] In 1901, 43·7 per cent. of the total number of deaths in mines were due to falls of roof and sides, and only 11 per cent. to explosions.

[2] *Transactions Inst. Mining Engineers*, xvii. 88.

The Sussman Lamp.—Another lamp which has met with success in mining work is the Sussman, which is in use at the Murton Collieries.[1] The lamp, as described by Mr. Wood, is made in two patterns—No. 1 with an ordinary or fixed bulb, and No. 2 with a top (patented by himself) containing a removable bulb, so that in the event of a bulb failing in the mine it can be replaced immediately by a new one.

The secondary battery is of the Faure or pasted type, consisting of two rectangular ebonite cells, each cell containing three elements (one positive and two negative) made of cast-lead plates or grids, with a stout framework tapering inwards and pasted with oxide of lead, incorporated with a special binding material and made into a paste with dilute sulphuric acid or sulphate of ammonia; the mass being pressed into the leaden grids and allowed to set and dry for four days. When dry, the plates are placed in a bath containing dilute sulphuric acid, and are then formed or converted, the positive into peroxide of lead, and the negative into spongy metallic lead, by means of an electric current.

These plates, connected by leaden strips, are placed in the cell, which is then filled with the electrolyte, a semi-liquid compound of dilute sulphuric acid and some absorbent.

The dimensions of the lamp are 2¾ by 2¾ inches by 8 inches high, and the weight is from 3 to 4 lbs.

The batteries maintain the charge for from eight to ten hours, and are then recharged by coupling up to a dynamo.

The following table given by Mr. W. O. Wood shows the cost of up-keep over a period of several months, including all charges except interest on capital and the cost of running the dynamo:—

	Pence per Week
All labour at basis rates, including superintendence, cleaning, making ready, maintenance, &c.	2·19
Material for renewing batteries, repairing, and maintaining the lamps in every part and lamp glasses	1·00
Incandescent lamps or bulbs	0·60
Total	3·79
With wages at 52 per cent. above basis rates the cost is increased by	1·03
Total	4·82

The life of the battery is said to be about twelve months.

Tests of Safety-lamps.—The following table[2] gives the result of tests made on various safety-lamps by the authors, and will be interesting as showing what electric safety-lamps will have to compete with.

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[1] 'The Sussman Electric Miner's Lamp,' by W. O. Wood; *Trans. Inst. M.E.*, xxi. 189.

[2] Originally published in the *Electrical Engineer.*

Name	Description	Weight before Test	Weight after Test	Difference	Time between Lighting and First Test	Approximate Cost of Eight Hours	Circular Area Lit
		Lbs.	Lbs.	Lbs.	Minutes	Pence	Degrees of Arc
Davy	Round wick, burning a mixture of 1 part paraffin, 3 parts colza	1·83	1·73	0·10	20	·233	360
Unbonneted Clanny	Round wick, burning a mixture of 1 part paraffin, 3 parts colza; plain clear glass	2·86	2·75	0·11	20	·256	360
Aluminium Deflector	Flat wick, clear glass, burning mixture of 1 part paraffin, 3 parts colza	1·83	1·74	0·09	20	·209	360
Thorneburry	Flat wick, 2 clear glasses; burns paraffin. Barton's burner	3·86	3·75	0·11	20	·126	360
Wolff's	Round wick, burning benzoline	3·45	3·39	0·06	20	·153	360
Ashworth's Uni-wick	Flat wick, burning mineral colza (paraffin)	3·33	3·22	0·11	20	·126	300
Ashworth's Tri-wick	Three round wicks, burning paraffin	—	3·55	—	—	—	300
Johnson	Flat wick, burning paraffin; reflector at back	3·48	3·37	0·11	20	·126	290
Morgan	Round wick, burning 1 part paraffin, 3 parts colza	3·44	3·34	0·10	20	·233	360
A. H. G.	Flat wick, burning mixture of 1 part paraffin, 3 parts colza; glass enamelled blue at back	3·80	3·72	0·08	20	·186	180
Bristol Electric	Rectangular brass case, 6″ × 2⅞″ × 2⅞″	5·16	5·16	—	20	—	180
Headland Electric (253)	Tall type, glass cylinder, metal shield	4·37	4·37	—	20	—	360
Headland hand lamp, not safety	Reflector type, wood case 4⅝″ × 3⅜″ × 2½″	2·32	2·32	—	20	—	120

Mixture of colza (3 parts) and paraffin (1 part)
Paraffin . . . .
Benzolene . . . .

NOTE.—These observations on candle-power must be considered in view of the fact that the light given powers of the above lamps would be greatly varied; generally, the benzene lamp gives the best light,

Time	Hours of Burning	Plane of Wick, Flat on	Plane of Wick or Filament, Edge on	Glass		Base of Lamp, Diameter	Size of Reflector	Remarks
				Height	Diameter			
		Candle-power	Candle-power	Inches	Inches	Inches	Inches	
11·0	0	—	0·2	—	—	3½	—	—
3·0	4		0·24					
7·0	8		0·16					
11·0	0	—	0·46	2	2½	3½	—	—
3·0	4		0·42					
7·0	8		0·40					
11·0	0	0·48	0·42	2	2¼	3¼	—	—
3·0	4	0·34	0·30					
7·0	8	0·45	0·42					
11·0	0	0·82	0·72	2¼	2¾	3¾	—	—
3·0	4	0·82	0·67					
7·0	8	0·54	0·53					
11·0	0	—	0·40	2	2¼	3½	—	—
3·0	4		0·42					
7·0	8		0·40					
11·0	0	1·0	0·95	2½	bottom, 2 top, 1½	4	2½ × 1¾	Reflector parallel with wick
3·0	4	0·95	0·87					
7·0	8	1·0	0·95					
6·0	0	1·1	1·2	2½	bottom, 2 top, 1½	3½	—	—
7·0	1							
11·0	0	0·90	0·96	2¼	2	3¼	2¼ × 1¾	—
3·0	4	0·89	0·77					
7·0	8	0·94	0·87					
11·0	0	—	0·44	2	2½	2½	—	—
3·0	4		0·37					
7·0	8		0·30					
11·0	0	0·22	0·21	2½	bottom, 2 top, 1½	3½	2½ × 180°	—
3·0	4	0·37	0·31					
7·0	8	0·35	0·31					
2·15	0	1·1	—	—	—	—	1¾	Three-cell battery: therefore 6-volt lamp used, which is more powerful than a 4-volt lamp. Volts at start, 5·94; volts at end, 5·16. Secondary battery
5·15	3	0·8						
9·15	7	0·54						
11·0	0	0·61	0·34	2¼	2½	3½	—	Two-cell battery or 4 volts; start volts, 4·08. Secondary battery
3·0	4	0·42	0·29					
7·0	8	0·34	0·16					
11·0	0	12·7	—	—	—	—	2¼	This is not a safety lamp, 2-cell battery, therefore 4-volt lamp used. Start, 4 volts. Secondary battery
3·0	4	10·9						
7·0	8	7·8						

Specific gravity

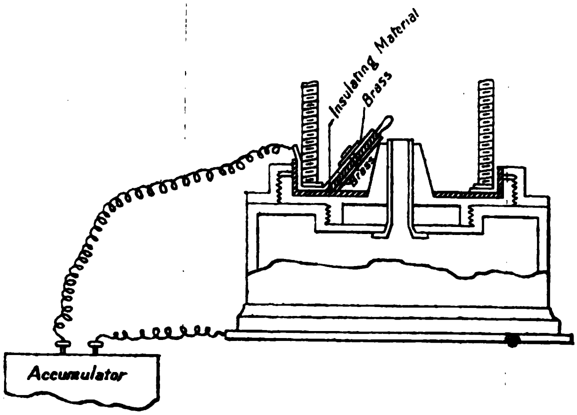
0·88 . .	2·33*d.* per lb.
0·785 . .	1·145*d.* per lb.
0·69 . .	2·56*d.* per lb.

by a lamp depends on the height of the flame, and that with a little change in that respect the candle-
taking the whole shift of work into consideration.

Lighting Oil Safety-lamps by Electricity.—An application of electricity which is widely used is an arrangement for lighting the lamp electrically. There are two principal methods in use, a high-tension current being used in one, and with this system the ordinary paraffin or colza-fed wicks can be lighted by means of a spark; the other system is to use a low-tension current and cause a platinum wire over the wick tube to incandesce and so light the vapour which is given off in a lamp burning light oils, such as colzalene.

The Protector Company were the first to sell a lamp of this kind lighted by an electric current heating a wire. When this kind of lamp-lighting is used, there are generally several lamp-lighting stations in the mine, where lamps can be re-lighted by the current from a secondary battery contained in a box; there are arrangements for prevention of sparking when putting the lamp on or removing it from the battery. The whole system was perfected under the direction of one of the authors; since then many modifications of these lamps have been introduced.

FIG. 157.



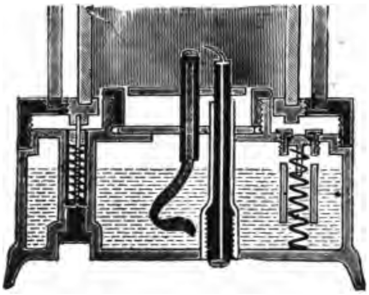
METHOD OF LIGHTING SAFETY-LAMPS.

Messrs. John Davis & Sons and others make an excellent type of low-tension lamp; it consists—as shown in fig. 157—of an ordinary safety-lamp with a platinum wire loop over the wick tube. One end of this wire is connected to a brass plate insulated from the rest of the lamp; the other pole is formed by connecting the other end of the platinum wire to the lamp body. It will be seen that by connecting the terminals of a battery to the brass plate and to the lamp body a current of electricity passes through the wire and makes it incandescent, so lighting the lamp.

Messrs. Ackroyd & Best make lamps on the high-tension system.

A section of the lamp bottom is shown in fig. 158, and it will be seen that there is an insulated conductor going through the oil-vessel with a pointed end extended over the wick-tube. The lamp body forms the other conductor, and on connecting the lamp to an accumulator and electric coil sparking takes place between the pointed conductor and the wick-tube, and the lamp is lighted.

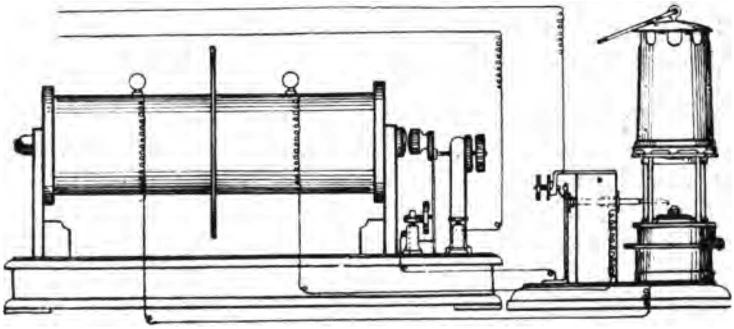
Fig. 158.



Ackroyd & Best's Electrically-lighted Safety-lamp.

Another form of high-tension lighting has been recently described in the 'Transactions Inst. M.E.,'[1] by Mr. Edward Brown. The apparatus (see fig. 159) consists of an induction coil connected up to a storage battery, or other source of electricity, in the usual way. A copper conductor is fastened into the glass of the lamp and extends so as nearly to touch the wick-tube. The lamp to be lighted is placed on an iron plate, and the circuit is completed by connecting one terminal of the induction coil to

Fig. 159.



Apparatus for Lighting Electric Lamps in Lamp Cabin.

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[1] Vol. xxiii. Part II. page 186.

this plate and the other terminal to the copper rod, and the sparking between the end of this rod and the wick tube lights the wick.

This apparatus seems to present a very simple means of lighting lamps in the lamp-cabin just prior to being given out; but in taking it down the pit it must be borne in mind that sparking will be produced outside the lamp, if connection is made, say, to the bottom plate and to one of the pillars supporting the bonnet, and the apparatus is, therefore, only suitable for a naked-light station.

With the low-tension system the spark on breaking the circuit will only be momentary, and will be much less powerful than with the high-tension system.

Electric Drills.—The application of electricity to drilling has been so far comparatively rare in the coal-mines of this country.

In those countries where metal-mining is largely carried on, and in coal-mining countries where the large number of faults entails the driving of long lengths of stone drifts, electric drilling machinery is more frequently met with. Under the ordinary conditions of many coal-mines, where, perhaps, the only shot-holes are in the ripping down of the roof in a long-wall gate, the use of electric drills would not effect a saving sufficient to justify the capital outlay; but where stone heads have to be driven, or in sinking shafts, and driving cross-measure drifts, their use might in many cases effect great economy.

There are two classes of drilling machinery—rotary, on the auger principle, and percussive.

The rotary drills are worked with most success in rocks of a comparatively soft nature. In the harder rocks the percussive drill is usually employed.

Electricity has also been employed successfully for driving the diamond drilling machinery used in prospecting; and quite recently the small diamond drill has been used in a Continental mine for boring in very hard rocks, such as granite, and it is quite possible that there may be a great future for such a machine in granite and slate quarries.

Electric Drills in the Cleveland Mines.—Mr. A. L. Steavenson, mining engineer to Messrs. Bell, the well-known ironmasters of Middlesborough, is largely responsible for the successful application of electricity to drilling, as employed in Messrs. Bell's Cleveland ironstone-mines.

The machines employed were originally driven by compressed air, but electricity is now used. And in this connection the following remarks of Mr. Steavenson are interesting:[1]—

'For twenty years compressed air had been used in mines, about two miles from one end to the other, with numerous machines, so that it was impossible to make a direct test, and say that they would start at a given hour and indicate every engine. He had managed to obtain a result by taking diagrams over several hours with each system of engines at bank, and these showed that with compressed air 111 h.p. was required for eight drills; with electricity, about 17 h.p. was required for the same work. The great loss with compressed air arose from the leakages of some eight or nine miles of pipes, whether the drills were cutting or not.'

---

[1] *Transactions Inst. of Mining Engineers*, xvii. 1898–9, page 222.

At the Cleveland ironstone-mines all classes of rotary drills have been used—the hand ratchet drill, the compressed-air rotary drill, the hydraulic drill, the petroleum-engine drill, and the electric drill—and the following table gives the result obtained with the several drills :[1]—

Description of Drill	First Cost of Machine only	Holes Drilled per Hour[2]	Ironstone got per Shift
	£		Tons
Hand Jumper . . .	—	4½ feet in 45 minutes	5 to 8
Hand Ratchet Drill .	3	Not yet known	About 18
Compressed-air Drill .	250	About 8 holes	100 to 130
Hydraulic Turbine . .	220	About 8 holes	100 to 130
Petroleum Engine . .	375	About 8 holes	100 to 130
Electric Drill . . .	350	About 10 holes	140

Fig. 160 illustrates the construction of the drill. The motor, M, is used to drive the drill-gear, and also acts as a counterbalance to the weight of the drill itself.

The armature-shaft is coupled directly to a shaft about 10 feet long, which passes through the long, hollow, carrying-bar, C. By means of bevel-gearing the vertical spindle, S, is made to revolve, and a bevel-wheel on this spindle gears into another bevel-wheel on the boring-bar, B, and so rotates the drill, D.

As the hole is bored the drill is automatically advanced by means of two pairs of gear-wheels, R R, the gear of which can be varied to suit the nature of the rock being bored. The nut, N, is thus made to revolve, and the boring-bar, B, advanced. As soon as a hole has been drilled the full length of the screw on the boring-bar, B, the split-nut, N, is opened, the boring-bar brought back, and a longer drill inserted.

In order to drill at various heights from the ground the machine is provided with a semicircular wheel, A, which can be moved by means of a worm. The machine will drill a hole 12 feet above ground level. The whole machine can be moved in a horizontal plane by means of the worm-wheel, W. The third worm-wheel, L, turns the long hollow bar, C, which carries the drill.

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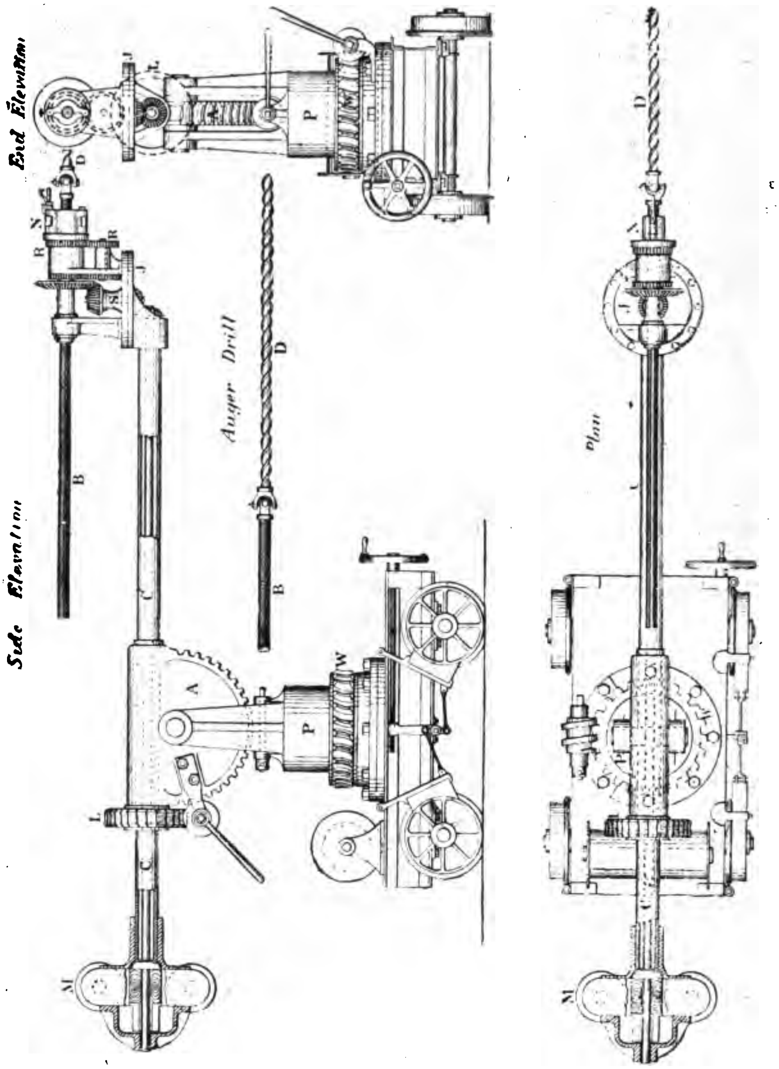
[1] 'Description of the Electric Rock-drilling Machinery at the Carlinhow Ironstone-mines in Cleveland,' by A. L. Steavenson ; *Proceedings Inst. of Mechanical Engineers*, August 1893. The figures are reproduced by their courteous permission.

[2] This includes the time lost in moving the machine to different working places.

The drill can also be moved in a horizontal plane on the plate, J, by unclamping a screw.

The drill is mounted on a trolley to run on the ordinary roads of the mine. The motor makes about 1,300 revolutions, the drill about 400 revolutions per minute. The voltage used is 300 at the dynamo, and the ampères absorbed by each machine are from 12 to 20, the motor being about 6 h.p. The holes are 1½ inch diameter, and they are bored at

FIG. 160

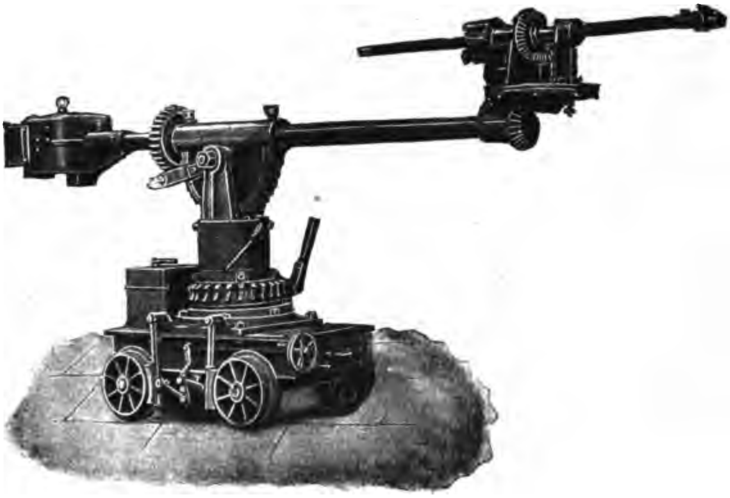


ELECTRIC ROCK-DRILL IN USE AT CARLINHOW IRONSTONE-MINES, IN CLEVELAND.

the rate of about 3 feet a minute. The weight of the machine is 35 cwt. The motors are completely enclosed, and the current is supplied through twin flexible cable, there being junction boxes in each district, so arranged that when the drill is moved from one working place to another a junction box is always to be found within 50 yards.

Fig. 161 is from a photograph of the machine.[1]

FIG. 161.



ELECTRIC ROCK-DRILL (see also fig. 160).

Grant's Electric Drilling-machine.—This machine is of the rotary type and is shown in section in fig. 162. The electric motor is connected to the drill by means of a telescopic shaft, and gives motion to the bevel-pinion, A, which gears into a bevel-wheel, which is fastened to the tube, B. The drill-spindle, C, is inside this tube, and is threaded along its entire length; it is also provided with two grooves in which the projecting keys, D, rest, and so the rotary motion of the tube, B, is imparted to the drill-spindle without preventing it from being moved lengthwise.

At the front end of the drill-case is the feed-nut, E, which is held in the nut-holder, F; the latter is connected to a sheave, H, which has brake-shoes J, working on its circumference. A wire rope encircles these brake-shoes, the two ends being taken to the two bolts, K; thus on tightening the wing-nuts, L, the brake-shoes press on the sheave, and prevent it and the nut-holder from revolving, and so the drill-spindle is caused to advance. The working parts being entirely enclosed enable the machine to be run in an oil-bath.

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[1] Lent by the makers, Messrs. Rosling & Fynn, Bradford.

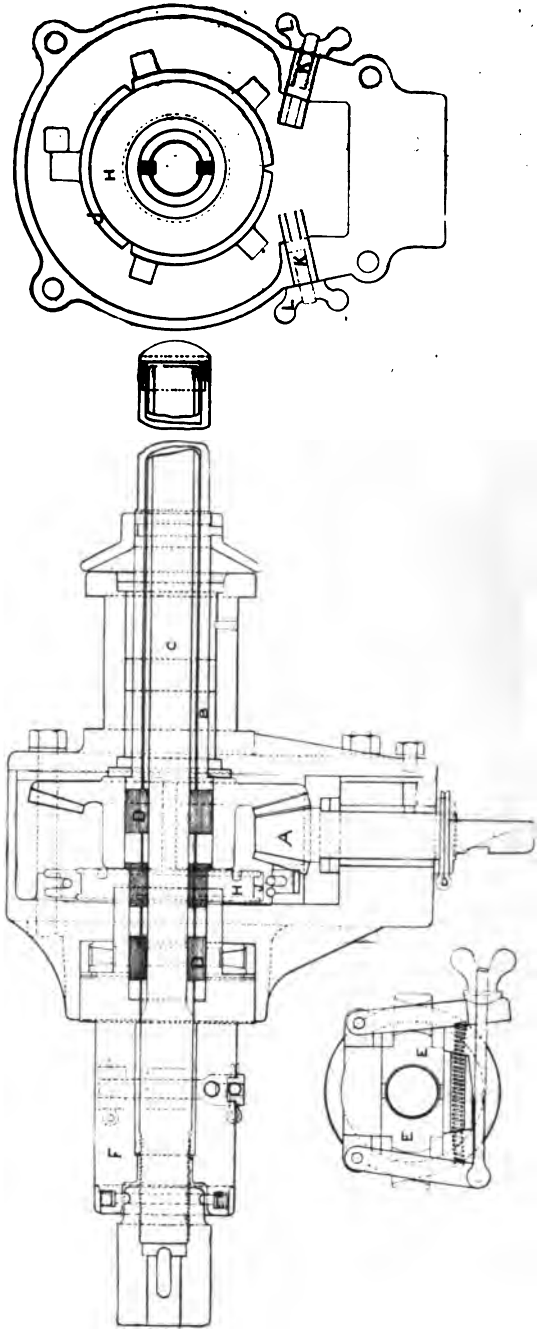


FIG. 162.

GRANT'S ELECTRIC DRILLING-MACHINE.

The standard motor is a continuous-current one of 4 h.p., and slow-speed (400 revolutions on full load), which enables it to be coupled direct to the telescopic shaft without intermediate gearing (see fig. 163). The ratio of the gearing in the drilling-machine is 4 to 1. The motor is series-wound, and this causes it to run at a higher speed when on light load, which is found to lift the dirt out of holes bored in a downward direction.

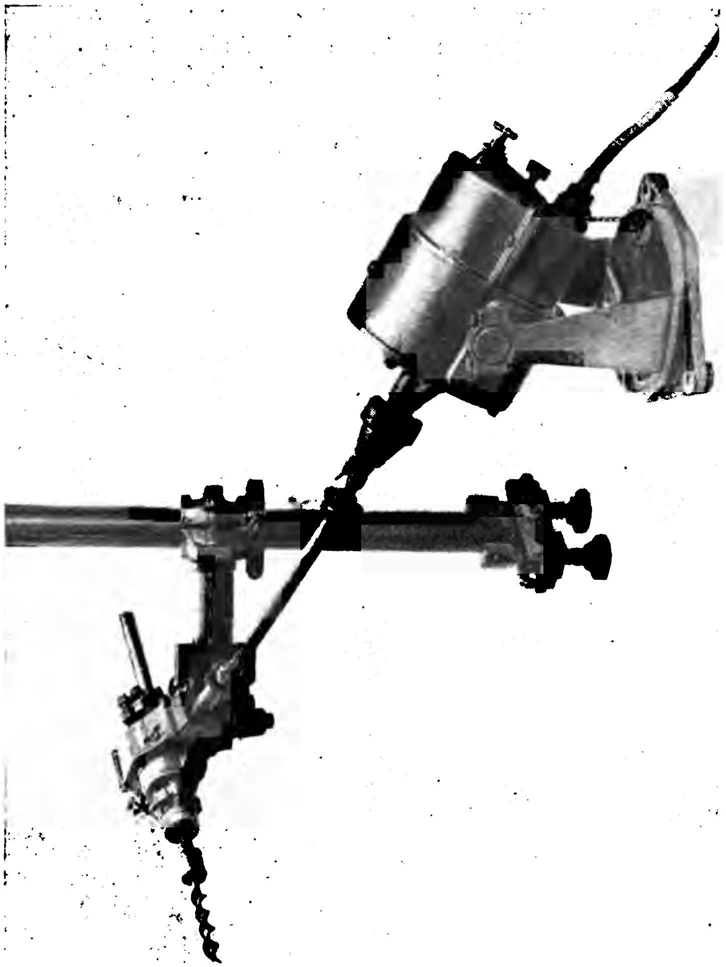


Fig. 163.

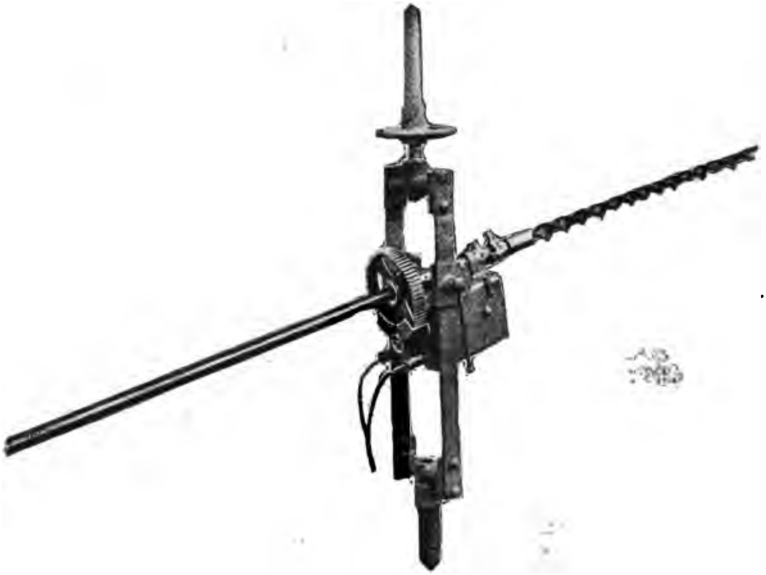
Grant's Electric Drilling-machine.

The drill-case is attached to a standard provided with the usual adjusting screws, and the motor is swung in trunnions attached to a turntable.

The weight of the drill is about 10 cwt., and with regard to the speed of drilling: it is stated that in a tunnel 12 feet by 6 feet two men can set up the plant, drill in fairly hard rock a round of 10 holes, each 5 feet 6 inches to 6 feet deep, $1\frac{7}{8}$ inch diameter, and clear away all their tackle for shot-firing, in eight hours.

The Jeffrey Drill.—This is essentially a coal-drill, and is largely used in the anthracite mines of America. The motor is series-wound, and is connected to the drill by gearing in the ratio of about $5\frac{1}{2}$ to 1. The drill is attached to a long screw with grooves in it, into which projecting feathers on the boss of the larger wheel fit loosely, and the feed is operated by a nut which is held in a friction-clutch which can be so adjusted as to cause the drill to slip upon encountering any hard substance which might be detrimental to it. The weight of the machine is about 170 lbs., and it is said to drill a hole 6 feet deep in less than a minute. An illustration of this drill is shown in fig. 164.

FIG. 164.



THE JEFFREY DRILL.

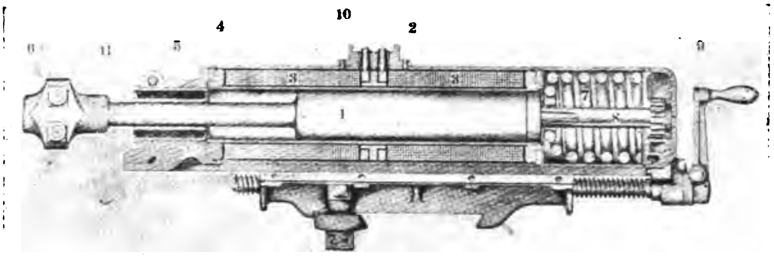
Other Rotary Drills.—There are other forms of rotary drill in use, but their principle is similar to those described above. Messrs. Ernest Scott & Mountain have supplied drills for use in the Rosedale mines of the Carlton Iron Company, while on the Continent Messrs. Siemens & Halske, of Berlin, have several rotary drills in operation in iron and salt mines.

Percussive Drills.—There are two forms of percussive drill. In one class the percussive action is got by electrical means, the Marvin and Depoele drills being examples of this class, in which the property of the solenoid is employed.

There are usually two solenoids, the drill being made of phosphor-bronze, with a short length of iron in the centre. The two solenoids are so arranged that by supplying the current to each alternately the drill is first advanced and then drawn back.

The Marvin Electric Drill, shown in fig. 165, has achieved success in American mines, and a number of these drills made by the Union Company are at work on the Continent. It consists of a solid steel plunger surrounded by two coils of wire through which electric currents are caused to pass. The coils of wire, by pulling the steel plunger backward and forward, produce the stroke of the machine. Referring to the figure, it will be observed that the plunger (1) of the machine is very similar to that of an air-drill; it has an enlarged portion (2), which is surrounded by the coils of wire (3, 3), and a shank (4), which passes through a bearing in the front head of the machine, and is provided with a chuck for holding the steel drill or bit.

FIG. 165.



MARVIN ELECTRIC DRILL.

The magnetic pull of the coils (3, 3) draws the plunger backward and forward as the current alternately passes through one or the other. The turning of the plunger is obtained by a rifled ratchet-rod (8) and ratchet-wheel. The spring (7) is a very heavy coil-spring, which is intended to check the backward stroke of the plunger and supply energy to the forward stroke.

The electric generator used is a two-phase alternating-current slow-speed machine, giving 135 volts. A 5-inch stroke drill will bore a hole 3 feet deep, $1\frac{1}{8}$ inch diameter, with about 4 h.p. An 8-inch drill will bore a hole to a depth of 20 feet with about 10 h.p.

The difficulty in practical working seems to be owing to the heating of the coils of the solenoids, and also that they have not the power of withdrawing the bit out of the bore-hole in case it should get wedged.

The other class of drills employ rotary motors, and have a mechanical contrivance to turn rotary into reciprocating and percussive movements ; and it is to this class we must look for future developments in electric percussive boring machines.

The Gardner Electric Percussive Rock Drill.—This is an American drill, at present being introduced into this country. It is said to have met with considerable success in the American mining districts.

Fig. 166 shows a sectional elevation and plan of the drill. The motor is enclosed in a box, the connection to the drill being made by a flexible shaft. This shaft imparts motion by means of a bevel-wheel to the bevel-wheel which is at the end of the driving-axle of the drill. The driving-axle passes through the crosshead of the drill and is cranked, the crank shaft working in a slot at the rear end of the crosshead, which is so contrived that one-fourth of a revolution of the axle-crank gives the full striking blow. The next half of the revolution withdraws the drill, during which the turning motion is imparted. During the remaining portion of each revolution the drill remains stationary.

On the opposite side of the axle is a gear which drives the fly-wheel, the latter being so arranged that it makes 1½ revolution to each revolution of the shaft. On the drill shaft are two springs which act as a buffer between the crank and the drill when striking the rock. A portion of the drill has a spiral groove in it, and by means of two ratchet-wheels, one left hand and the other right hand, the drill is rotated after each blow. The machine is carried on a vertical standard, and is provided with a feed-screw and handle, by means of which the drill-cylinder can be advanced as the hole gets deeper. The machine is made in two sizes. One size, for general work, weighs 150 lbs., will cut holes up to 5 feet deep, requires a 1 h.p. motor weighing 175 lbs., and strikes 600 blows per minute with a 2½-inch stroke. The other size, for heavy work, weighs 260 lbs., will cut holes to 8 feet deep, requires a 2 h.p. motor weighing 225 lbs., and strikes 500 blows per minute with a 3-inch stroke.

The drill has so far hardly had a trial in this country, but it seems mechanically good, though no doubt some arrangement for automatically clearing the hole would be an advantage.

Electric Welding.—At a large colliery a system of welding by electricity could no doubt be adopted with advantage. One chief advantage seems to be that awkward breaks, which cannot be welded in the ordinary way, can be welded by electricity, and also that repair work can be just as easily done underground (when there is no danger of igniting gas) as on the surface. The electric arc can be used for cutting metals, such as girders or plates, and this operation can be done *in* *situ* when it is not possible to bring the work into the shop. Sections such as are used in making the top and bottom frames for cages, channels,

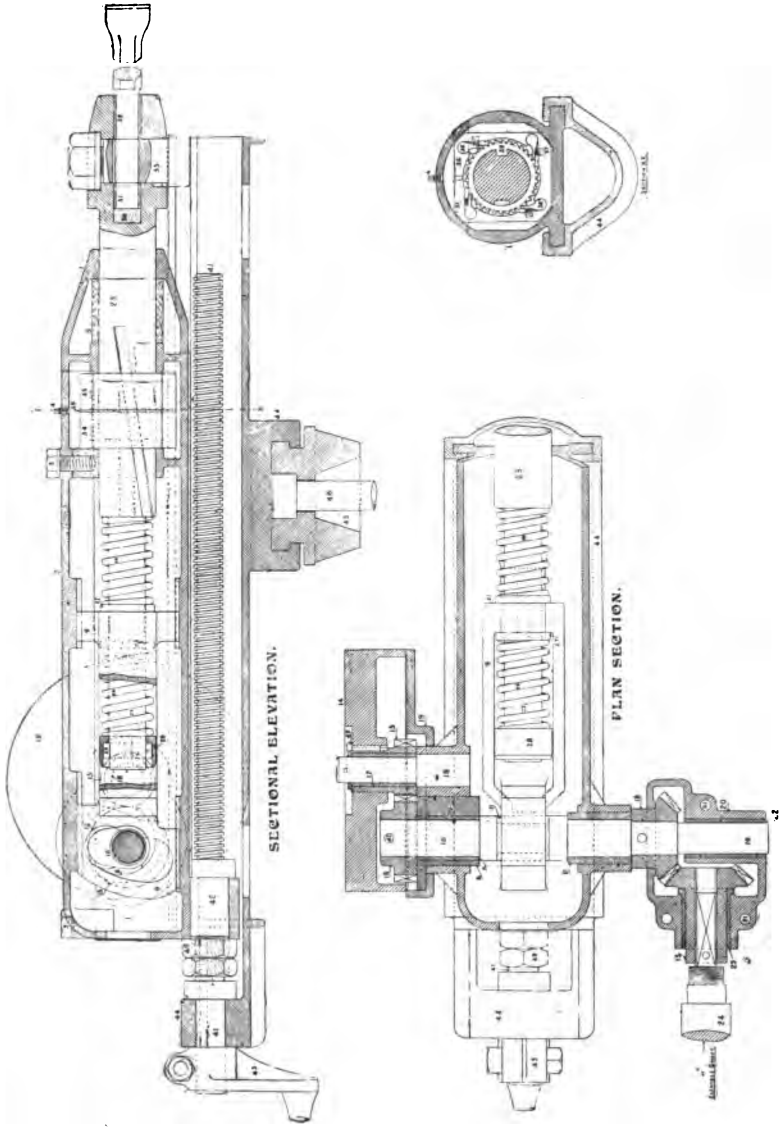


FIG. 166. GARDNER ELECTRIC PERCUSSIVE DRILL.

angles, &c., can be conveniently welded by electricity, and cracked arms of fly-wheels or drums can be repaired by filling the crack with small chippings of metal and subjecting the whole to the electric arc. While it would not, of course, pay to introduce an electric current merely for the sake of occasional electric welding, yet where the dynamo is already installed for haulage, pumping, or lighting, an electric welding plant will be found a useful accessory.

There are two systems of electric welding—the Benardos or Arc system and the Thomson system. In the Arc system the heat is generated by making the article to be operated upon one pole of an electric circuit, while a carbon pencil attached to a portable insulated holder constitutes the other pole, and an electric arc is formed which produces the heat necessary for the weld.

In the Thomson system currents of electricity are passed through the abutting ends of the pieces of metal which are to be welded, and so heat is generated at the point of contact, while, at the same time, pressure is applied to force the two parts together.

The Benardos System.—The plant consists usually of low-tension continuous-current dynamos, which during light load are employed in charging accumulators. The dynamos supply the current direct to the welding machines, and when extra current is required a demand is made on the accumulators. A flexible cable goes from the dynamo to a carbon pencil held in an insulated holder, which is in turn held by the workman, while the other terminal is connected to the table on which the work lies or to the work itself. Each welder has a regulating resistance, so that the current and pressure can be varied to suit the work.

The voltage used in the Benardos system is about 85. It is necessary that the eyes and face of the workman should be covered to protect them from the glare of the arc.

The Benardos system is employed at the works of Messrs. Lloyd & Lloyd, Birmingham, and that firm have made many tests which prove the capabilities of the process. Two hundred and ten bars of iron and steel of varying thickness were electrically heated and welded by ordinary workmen (not trained smiths), and, together with fifty bars welded by good engine-smiths, were submitted to tensile tests. The average strength of the 150 electrically-welded iron bars equalled 85·5 per cent. of the solid, and of the sixty electrically-welded steel bars 80·8 per cent., which was a higher result than was obtained in the case of the hand-welded bars.

A modification of the Benardos system is called the Deflected Arc system. The dynamo mains are connected direct to two terminals similar to an ordinary arc lamp ; but on one side of the arc an electro-magnet is arranged, through which a portion of the electric current is sent. This magnet draws out the flame of the arc. It will be seen that in this system the article to be welded is not connected in any way to the dynamo, and the arc can be moved nearer to, or further from, the article, and the temperature varied in this way.

The Thomson System.—This system is used by the Electric Welding Company. The plant consists of a generator producing low-pressure alternating currents, a rheostat and reactive coil for controlling the current in the welder, a transformer provided with clamps to grip the pieces to be welded, and mechanical (sometimes hydraulic) arrangements by which the abutting ends of these pieces are forced together.

The transformer converts the current—which is delivered to it at a voltage of about 200—down to about 1 volt, with the result that a current of very great strength passes through the metals to be united, and raises their temperature to that requisite for welding.

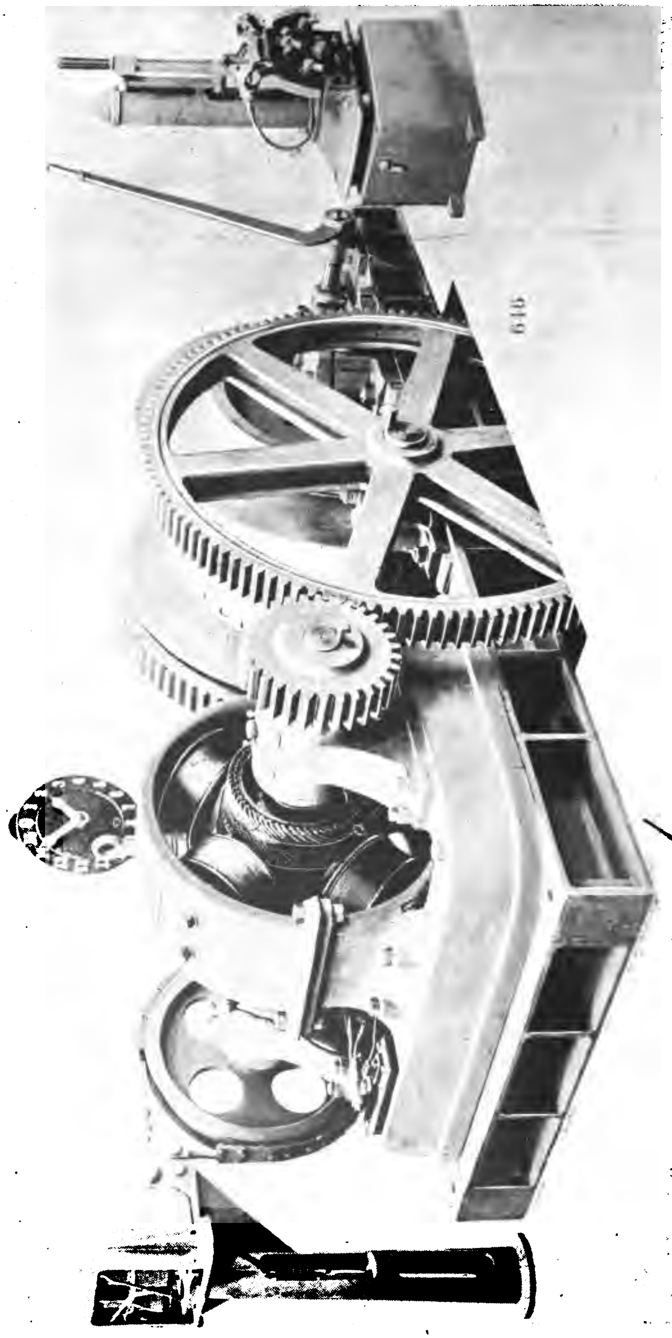
Electric Winding.—Electricity has not come largely into use for winding, owing to the reasons given on page 136. There are some small plants in operation in this country, and on the Continent large plants have been built. Fig. 167 illustrates an electric winding gear which has been made by Messrs. Ernest Scott & Mountain for the Heckmondwike Collieries for winding from a staple pit about 100 yards deep. The gear is driven by a four-pole open-type motor, capable of working up to 50 effective horse-power at a speed of about 600 revolutions per minute. At the end of the motor-shaft an automatic electric brake is fitted, which sustains the load immediately the current is switched off. The coils of the electro-magnet of this brake are in circuit with the armature of the motor, and immediately the current is switched on to the motor the armature is attracted by the electro-magnet and releases the brake-wheel.

The motor drives through a train of gearing (the first-motion pinion being forged steel, machine cut) into a machine-cut cast-iron spur wheel, which is supported by a counter-shaft on which a pinion is carried, gearing into a spur wheel on the drum shaft. The drum is 3 feet 6 inches diameter by 2 feet wide, lagged with elm, and has strong cast-iron sides, a brake-strap being fitted on one side, which is controlled by the attendant. An indicator is provided which shows the position of the cages in the shaft; this is driven by machine-cut wheels from the shaft.

The whole gearing is mounted upon a cast-iron bed-plate made in sections for getting down the pit and into position by the staple. The motor on the winding gear is controlled by a liquid reversing and regulating switch. A Scott & Mountain 50 k.w. multipolar dynamo supplies current to the motor.

The Gelsenkirchener Bergwerks-Aktiengesellschaft work all the machines at their new Zollern No. 2 pit electrically, and there was exhibited in the Dusseldorf Exhibition (1902) a winding engine, which was at the close of the Exhibition to be erected at the above pit. The Koepe system of driving pulley is used, the pulley being about 20 feet in diameter. There are two electric motors, one on each side of this pulley or drum, on the same shaft. Direct current is employed, the voltage being 500. Each

Fig. 167.



Electrically-driven Winding Gear.

motor has a maximum power of 1,400 h.p. The motors are used in conjunction with a storage battery, which is gradually switched on. The load of coal to be lifted is 4,200 kilogrammes, equivalent to about 4 tons, from a depth at first of 280 mètres, and ultimately from a depth of 500 mètres (546 yards), with a maximum speed of 20 mètres a second. There is a compressed-air starting and reversing engine, and a compressed-air brake.

CHAPTER XIV

[illegible] WITH OTHER MODES OF [illegible] POWER

[illegible] compressed air—Hydraulic—Gas and Oil.

[illegible] may be various, and are generally as [illegible]

[illegible] waterfalls and windmills; steam boilers [illegible] of the whole quantity. [illegible] gas generators may to [illegible] steam boilers.

[illegible] steam boilers are all close together at the base of a [illegible] the steam are scattered about over [illegible] on high ground or on [illegible] shafts and other machines [illegible] dangerous to convey steam.

[illegible] power from the boilers to the machines [illegible] every mine manager, and the [illegible] following headings :—

[illegible]

[illegible] steam-engines.

[illegible] steam-engines.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] Steam Transmission [illegible] most obvious, the [illegible] danger except in [illegible] where an escape of [illegible] underground. [illegible] Steam has been conveyed a [illegible] great waste of power. [illegible] from the pipes. The [illegible] be much reduced by covering the pipes with non-conducting material. It is difficult to measure the amount of loss. The amount of water formed in the steam-pipes which may be caught in a cistern and taken out and measured does not represent the total loss, because a considerable amount of water passes through the steam-engine. The percentage of loss varies inversely as the amount of power transmitted—that is to say, the greater the amount of power transmitted the less will be the percentage of loss. The loss is constant for a given length, size, and temperature of pipe, but the power varies with the speed at which the steam passes through the pipe and the regularity of its passage; thus, if the steam is passing through the pipe at full speed the whole twenty-four hours, the amount of condensation might be, say, 20 per cent.; but if the steam were only passing through at full speed for twelve hours, and the other twelve hours only little more than sufficient to warm the pipes, there would be as much steam lost as in the first case; but, as there would only be half the power, the percentage of loss would be 40, and if the total amount of power transmitted only represented eight hours' full work out of the twenty-four, then the loss would be increased to 60 per cent. The above figures are all hypothetical.

Loss from the steam-pipe increases directly with its length and circumference, but the percentage of loss decreases as the diameter increases, if the diameter is properly proportioned for its work. That is to say, a 4-inch pipe, having twice the diameter of a 2-inch pipe, exposes twice as much surface for cooling, but it will allow five times as much steam to pass with the same percentage of frictional resistance as the 2-inch pipe; therefore, if the 2-inch pipe and the 4-inch pipe were each transmitting the full amount of power for which they were suited, the percentage of loss in the 4-inch pipe would only be two-fifths of that in the 2-inch pipe—*i.e.*, if the loss in the 2-inch pipe was 50 per cent., the loss in the 4-inch pipe would be only 20 per cent., the other circumstances being the same. When, however, a pipe is covered with non-conducting material, the surface exposed to the air does not vary in the same proportion as the internal diameter of the pipe, because the thickness of the non-conducting composition has to be taken into account; and if the 2-inch and the 4-inch pipes were made of cast iron $\frac{1}{2}$ inch and $\frac{3}{4}$ inch thick respectively, and were each covered with 1 inch of non-conducting material, the external diameters of these pipes would be 5 inches and $7\frac{1}{2}$ inches respectively—*i.e.*, the radiating surface of the 4-inch pipe, instead of being twice as great as the 2-inch pipe, would be only 50 per cent. greater. The foregoing remarks show that steam transmission may be economical with a large power and wasteful with a small power. On the other hand, it must be borne in mind that a large steam-pipe in a mine might be dangerous if taken a long way into the workings, and that the immunity from serious accidents in the past is very likely due to the fact that it is seldom that a large steam-pipe is taken far from the pit bottom. One objection to steam-pipes is that an exhaust-pipe is generally necessary for the return of the steam, except in those few cases where all the steam can be condensed, as is the case with pumping-engines where the height to which the water is raised is very low.

No. 2. Transmission by Rods.—In this case a crank driven by a steam-engine gives a backward and forward movement to a connecting-rod carried on vibrating levers. Rods may be joined together end to end, carried on levers, and the power transmitted for great distances on land, or down a pit and along the underground roads. Corners may be turned by bell-crank levers. This arrangement is good for certain cases, but is seldom adopted nowadays on account of the ponderous nature of the connecting-rods when they are of considerable length, and the room occupied, and the awkwardness of using the reciprocating motion for any other purpose than that of pumping water.

No. 3. Transmission by Wire Ropes is very largely used both for carrying power on the surface and transmitting it down the shaft of a mine and along the levels and inclines. Wire-rope transmission is of two kinds. The first is where the wire rope which is connected to the drum of the engine at the boilers is the same rope that does the work underground for which power is required. This is the case where underground or surface haulage is done by one rope. If the rope is used for endless-rope haulage, the speed is generally slow; if for single-rope or tail-rope haulage, the speed is generally fast. The second method of using wire-rope transmission is where the rope is merely used like a strap or belt in a factory, for transmitting the power from the steam machine by the boilers to some other machinery in the pit. In this case the strap-rope is generally high-speed; the higher the speed the lighter is the machinery and the smaller the rope necessary. Some engineers prefer a thick rope and slow-speed machinery. Next to steam transmission, the wire rope is the cheapest mode of transmitting power, as regards first cost. All that is necessary is the driving-wheel, or drum, on the generating engine, and the receiving-wheel, or drum, on the machinery in the mine, the various guide- and angle-pulleys on the way, and the rope itself. This method of transmitting power is therefore very largely used, and is particularly applicable where the number of turns in the direction of the rope is not great. In some cases on the surface the rope may be carried in the air without any guide-pulleys from the generating engine to the receiving machine. In such a case as this it is probably the most economical mode of transmitting power that is known. But these cases are rare. From the mine manager's point of view the objections to the rope transmission are the space required in the shaft for the ropes and the space required in the underground roads for the supporting pulleys and turn-wheels, and the complications of subsidiary driving- and receiving-drums where the machinery to be worked is scattered in many directions and places. There is also the question of the safety of men in the shafts down which the strap-ropes are working, and the necessity for boxing up the ropes. Where, however, strap-ropes can be conveniently used, it is doubtful if any other means of transmitting power is more economical. It should, however, be noted that in many places they have been superseded by electricity.

No. 4. Compressed Air is very largely used, and is the most obvious means of superseding steam transmission. The same arrangement of pipes will do in each case, but instead of the steam going direct from the boiler, it goes into an air-compressing engine, and compressed air is taken into the pipes which go into the mine. The advantages of compressed air are very great. A mine is generally warm; compressed air helps to cool it. An escape of compressed air, though it means a loss of power and of money, is otherwise beneficial in a mine. It is useful, not merely for power, but for ventilation in confined places. On the other hand, it is very costly. The air-compressing engines and the air-using engines or air-motors, cost a great deal more than the steam-engines which they would supersede. It may be taken that the air-motor is equal to the cost of a steam-engine which would have done the work, but on the surface we have the air-compressing engine, and this probably costs five times as much as the steam-engine would have cost to do the work direct had steam transmission been used. Also, owing to the loss of power in air-compression, there will be a great increase in the outlay for boilers; but that increase is uncertain, because the loss by steam transmission might have been so great as to equal the loss by air-compression, or even to exceed it, so that, as compared with steam transmission, it does not follow that the boiler cost would be increased, but the boiler cost would be greatly increased as compared with rope transmission. In working cost the loss of power depends on many circumstances, some of which are under the control of the engineer. They are as follows :—

1. Leaks in the pipes. This is entirely a question of management. It is not necessary that there should be any leak, and, if existing, it may be easily discovered.

2. Friction of the air transmitted in the pipes. This can be reduced to a very small percentage by having the pipes of sufficient diameter. The friction varies inversely as the fifth power of the diameter, so that a very small increase in the diameter is sufficient to make a very great reduction in the loss through friction. The fifth power of five is 3,125, and the fifth power of six is 7,776, so that if with a 5-inch pipe the friction had required a pressure of 7·77 lbs. to overcome it, if a 6-inch pipe were substituted, a pressure of only 3·12 lbs. would be required.

3. Heating of the air during compression—the necessary abstraction

of this heat from the air, which heat is necessary for the free expansion of the air in the motor, and is not there when wanted. The loss due to the generation of heat may be reduced by efficient cooling of the cylinder and by stage compression, but this loss may be expected to amount to 25 per cent. of the engine power. The useful effect of the power of the air-motor, as measured by a friction-brake, cannot be expected to be more than 40 per cent. of the I.H.P. of the air-compressing engine.[1] In some cases the useful effect is only 10 per cent., in many cases only 20 per cent.; 30 per cent. is considered a good return.

If compressed air is used on the surface, or in some place in the mine where there is no danger from fire and smoke, then it may be re-heated before entering the air-motor. In that case, the power which was taken out of it on compression can be restored, and, indeed, more than restored; this involves an expenditure of fuel; but the efficiency of such an air-engine is so great that the cost of the fuel used in re-heating becomes insignificant, and, where re-heating by means of a fire is admissible, compressed-air transmission is exceedingly efficient, and it is not probable that the efficiency can be exceeded by any other means. But it rarely happens that re-heating by fire is admissible. Compressed air is applicable to almost every species of machine used by miners.

No. 5. Hydraulic Transmission of Power.—In this case the generating engine, instead of compressing air, pumps water, which is incompressible, along pipes. The water is pumped against a heavy 'head' maintained by accumulators, and the pressure used generally varies from 500 lbs. to 1,200 lbs. on the square inch. It is largely used in docks for working hoists and capstans, and small motors for opening and closing dock gates. It is also used for driving motors in warehouses and elsewhere. It has many advantages and conveniences, but for mining purposes it is not generally so convenient as compressed air. It is generally necessary to have a return pipe for the exhaust water, and, being non-elastic, it is often used at full pressure when one-half or one-quarter of the full pressure would be sufficient. In cases where a single generating engine on the top forces water through a pipe to drive a single pump at a distance in the mine, the power of the generating engine may be exactly that which is necessary for driving the pump at a distance without any waste power. In such a case as this the efficiency of a hydraulic transmission system would be greater than that of compressed air (except where re-heating is admissible), and probably at least equal to that of any other system of transmission. But the mine manager, as a rule, desires a system of transmission of power applicable to a great variety of motors working at various speeds and in places far distant one from the other. Hydraulic transmission is not generally suitable for very large powers, but is best employed for those cases where a small power constantly generated at the central station can be applied to exerting great efforts for very short periods.

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[1] *Mining*, by Lupton, p. 369.

No. 6. Transmission of Power by Gas and Oil.—The last forty years have witnessed a great development of gas-engines. These engines are made suitable for using not only illuminating gas, but any other kind of inflammable gas. The cheapest kind of gas is that known as 'producer' gas. This gas, when once produced and purified, may be transmitted to any distance in pipes, and the gas-engine can be erected at the place where the work is required. The main objection, however, to the transmission of 'producer' gas to a great variety of places is the poisonous nature of this gas, which contains a large percentage of carbonic oxide gas, called by chemists carbon monoxide, and shown by the chemical symbol CO. For this reason, as well as for its explosive quality, no mine manager would think of taking the gas down the pit; and if he wished to use a gas-engine at all, he would only use it at some engine-house so situated and ventilated that the danger of poisoning or of explosion was reduced to a minimum. A gas-engine might very properly be used at a central power-generating station, for generating power to be transmitted either by wire ropes, compressed air, hydraulic pressure, or electricity, and in this way probably it will be largely used in the future.

If we talk of conveying power by means of gas, which is to be burnt in the cylinder of an engine at a great distance from the gas generator, it is reasonable to talk of conveying power by oil, not conveyed in pipes but in barrels to the place. The oil, on its way into the cylinder of the engine, is vaporised, and therefore for practical purposes becomes a gas in the cylinder of the engine. The oil-engine is very useful both in the pit and on the surface. It can, however, only be used in those situations where the exhaust will do no harm. Although the exhaust from an oil-engine is not poisonous, still it does not conduce to the health and strength of those who breathe it, and is unsuitable for discharge into an air course conveying air to working places. It should, therefore, only be used where the exhaust is discharged into the return. An objection to the oil-engine is the amount of fire required to start it, a large oil flame being required to heat the vaporiser until the engine has got fairly to work. This is enough to prevent it becoming very popular in most collieries, and in a great many other mines where fire is the most dreaded risk; but the economy of oil-engines is such that for surface work it will be difficult to provide anything more cheap in working cost. Oil-engines, however, as well as gas-engines, are rather troublesome to start, and for that reason, when once started, are generally kept running through the day, and, as usually made, are not suitable for reversing, although the reversing can be effected by means of suitable gearing.

No. 7. Electric Transmission, twenty years ago, was both novel and rare; it is now well established and very common. It cannot be said to have superseded wire-rope transmission, but it has come into favour in comparison with transmission by steam and compressed air; indeed, the real contest for superiority lies between compressed air and electricity. The advantages of electrical transmission may be stated as follows :—

1. Electrical generators are revolving instead of reciprocating like most air-compressors,[1] and there is generally much less wear and tear about a steadily revolving machine than about a reciprocating one; and consequently the engine driving it may go at a much greater speed than is practicable with a reciprocating air-compressor, which tends to reduction in the comparative size of the electric generating machinery.

2. The electric conductor is more quickly and conveniently taken down pits and along roads and round numerous corners than compressed-air pipes, and occupies less space.

3. The efficiency of transmission by electricity is greater than with compressed air (except where re-heating is permissible). The efficiency of an electric dynamo varies from about 80 to about 95 per cent. of the power put into it, and the efficiency of the motor is about the same. The loss in transmission through the cables is probably about equal to the loss that takes place in compressed-air transmission through pipes, and may be much or little according to the amount of money laid out upon the cables. Electricity has the power to adapt itself to the amount of work required, similar to the elasticity of compressed air. The cost of an electrical installation is probably rather more than that of compressed air, but very few mining engineers would to-day put down an air-compressing plant in preference to electricity, unless the particular situation of their mine made electricity peculiarly dangerous.

The drawbacks to the use of electricity are gone into in Chapter XV.

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[1] Messrs. Parsons, of Heaton Works, Newcastle-on-Tyne, make a revolving air-compressor, being one of their turbines reversed.

CHAPTER XV

DANGERS OF ELECTRICITY

Dangers of Electricity—Methods of Obviating the Dangers—Testing of Cables—Wheatstone Bridge—Ohmmeter, &c.

EVERY new method or appliance involves new dangers. Perhaps these new dangers may be less than the old dangers, but they are none the less real.

Fire.—At a mine, one of the most terrible dangers is that due to the burning of woodwork or coal. The reason of the great danger is because of the strong current of air passing through the mine, which supplies the oxygen necessary for rapid combustion, and also the fact that there may be no possibility of escape from the mine without passing through a burning fire on the one hand or a suffocating smoke on the other. This danger applies equally to underground mines of all kinds which contain inflammable material such as timber. It also applies with greater force to collieries, because here the fire, once started, may take hold of a great mass of coal. The danger is not limited to the underground works, but also exists on the surface works. At the top of the pit there are frequently a great many buildings and machines, and if in and about these there is inflammable material such as wood and coal, the smoke and flame from these, when once set on fire, may be drawn down the shaft with the ventilating current, and may cause a terrible disaster. For this reason the mining engineer, when deciding to use electricity, must spare no reasonable precaution to avoid danger from fire.

Arrangement of Cables to Avoid Fire.—If well-insulated cables are used on the pit top, they may be carried from the generator safely past all the buildings and woodwork by being placed in the earth, care being taken to avoid the proximity of any wooden posts, or any ground containing coal, pit shale, or other inflammable material. If this is carefully done, the electric cable, however defective it may be or become, will not set fire to anything, for the simple reason that there is nothing near it which it can fire.

Another method is to lay the conductor in pipes in the ground. These pipes may be of iron or earthenware, care being taken that the pipes do not go too near to any timber, coal, or pit shale ; but even if the pipes do pass some coal or similar inflammable material, it is not likely that they will cause a fire, because the current in passing through the earth will be spread over too large an area to cause great heat in the earth. The pipes may be laid in a bed of sand, clay, gravel, or ashes.

A third plan is to lay the cable in a brick culvert, which contains no timber crossbars or other inflammable material, the crossbars being made of iron, and the cables carried on porcelain insulators. Care must be taken to exclude coal-dust from this culvert, and therefore it must not have an open end near to the screens, so that a current of air from the coal screens would carry dust into the culvert. It is well known that coal-dust from screens is easily inflammable, and explosive when mixed with air. The culvert must also be ventilated, so that no accumulation of gas can occur.

If the conductor is carried overhead, on poles or otherwise, it must be so carried that in case of defect in the insulation the current will not come in contact with any wood, coal-dust, coal, or inflammable shale. The conductor must also be carried in such a line that in case it should be broken, either by its own weight or the weight of snow, or by some weight accidentally or carelessly falling on it, it will not in falling come in contact with any wood or other inflammable material. There may be some difficulty in fulfilling this condition, but the difficulty must be overcome.

Fireproof Generator-house.—The dangers from fire on the surface are not only in the conductors, but are to be found in the generators, terrible accidents having arisen from generators placed in engine-houses near to the pit top. For this reason the generators should always be placed in buildings which are entirely separate from all inflammable materials at or about the pit top, so that a fire originating at the generator or in the generator-house cannot possibly extend to the winding-engine, pit bank, &c., and cannot extend to heaps of pit timber, shavings, &c. Accidents from electric dynamos, as from other causes, nearly always arise in some manner that ordinary human intelligence does not foresee. In a new installation there is no difficulty in having a complete fireproof separation between the generators and the rest of the plant at a mine.

Fireproof, &c., Motor-rooms.—The precautions which are necessary for the generator must be observed as far as practicable with the motors ; but the danger from a motor is much less than from a generator, because if there is any defect in the insulation of the conductors it is likely to lead to the stoppage of the motor and the current, whereas, on the other hand, it would not stop the generator or the current generated. But still every reasonable precaution must be taken in fixing up motors at or about a pit top. They should be placed as far as possible on foundations of stone, brick, or concrete, and walled round with similar non-inflammable material, and the roof carried on iron instead of wood; it being always remembered that near the top of a coal-mine there may be under every roof an accumulation of coal-dust, which is easily fired, and in its turn will set fire to woodwork. Where brick, stone, or concrete cannot be used for the support of the motors and for surrounding them, they should be placed upon iron plates and surrounded with iron plates, so that in case of a short-circuit causing an electric arc, or other dangerous passage of electricity, there will be no inflammable material to catch fire. To place electric motors and conductors anywhere about wooden pit frames, screens, &c., near a pit top, is to court terrible disaster.

Fuses, &c.—At a generating station there are fuses and automatic circuit-breakers, the intended effect of which is to shut off the current in case of an excessive amount passing through any conductor owing to a short-circuit or any other cause, such as an overload on a motor; but in the case of a circuit where there are, say, half-a-dozen motors, either in parallel or series, there might be a short-circuit at one of these without the amount of current being necessarily so large as to cause the circuit-breakers or fuses at the generator-house to act. There ought to be a circuit-breaker and also a fuse in an air-tight iron case at each branch, so that every provision may be made to avoid any evil consequences from a short-circuit at the motor or in the conductors, just as if it was certain that the generator would continue to send the maximum possible current.

The many fires that have originated at mines through the use of electricity have arisen from the inexperience of mining engineers and mine managers, and also from the fact that the advocates of the use of electricity and the vendors of electrical machines have not sufficiently dwelt on the dangers against which provision must be made, and also from the fact that the mining engineer is frequently induced to adopt the use of electricity by representations as to the cheapness with which the conducting cables can be carried about the works, and the convenience with which electric motors may be placed on stages and in corners of buildings. But when it comes to carrying out the work, it appears that if it is executed with every precaution that prudence can suggest, it is much more costly than appeared from the original estimates.

The mining engineer must treat electrical generators, conductors, and motors as if they were fires, because they may become fires. Having once made up his mind so to deal with electric appliances, and having in consequence made the proper arrangements, it is probable that he will never have a fire, or any serious difficulty with his electrical plant.

Conductors in Vertical Shafts.—The dangers arising from electric cables in a vertical shaft, as a rule, are not so imminent as those on the pit top, because the shaft is usually damp, and frequently wet, and if it is walled with brick or stone there is nothing to burn. But in the case of a shaft lined with timber, and which is not permanently wet, then the utmost pre cautions must be taken to avoid fire. Sometimes a bare copper cable is stretched from top to bottom of the shaft, and is not in contact with any material at all. In such a case as this, no accident can arise from the cable unless it should break, or be brought in contact with some conductor, such as one of the cages, or a metal trunk, swinging against it. In case both conductors should break, no electrical damage (except the spark on the breaking of the circuit) would happen in the shaft or below, because the circuit would be entirely cut off. In case one conductor should break and fall down, then the part at the pit bottom would be earthed, but if the end at the pit top remained well insulated the circuit would be broken and no current would flow; but if there was a fault, then the current would flow through this fault, and the cable would very likely get hot. In brick-lined shafts a heavily insulated cable is often carried down in a species of wooden pipe. In case from any defect a short-circuit should happen, and if the shaft was perfectly dry, the wooden box might be fired. In an ordinary brick-lined shaft, it is not likely that any very serious results would follow, but if the shaft was lined with dry timber the consequences might be disastrous. In order to avoid this danger it would be better to have the cables covered with armour of galvanised-iron wire, instead of covering them with wooden boxes; and in case, owing to the depth of the shaft or other circumstances, it is necessary to support the cable in the shaft, it can be fixed to porcelain insulators. If the shaft is wet, the wooden boxes will not be any source of danger If the shaft is dry, the galvanised-iron armouring will last for a great many years.

Cables along the Passages of a Mine.—The dangers due to these cables are in the first instance those arising from the use of bare wire conductors, and would be due in that case to overheating through excess of current, causing coal-dust or other inflammable material in contact with the wires to take fire. The dangers due to bare wires, however, are so obvious that it it is seldom, if ever, they are used in a coal-mine, so we will consider the dangers due to the use of insulated cables. These are, firstly, due to excess of current causing heating of the cable. This, in the case of a main cable, can be met by the fuses or automatic circuit-breakers at the generator-house, which will cut off the current as soon as it becomes excessive. The next danger is that due to some defect in the cable causing an escape of current to the earth. In the case, however, of all ordinary arrangements, where the generator is not connected with the earth, a defect in one cable is not sufficient to cause a current to the earth. There must be a corresponding defect in the other cable, which also then connects with the earth, and the current goes from one cable through the earth into the other cable, thus causing a short-circuit. Suppose, for the sake of argument, that the motor being supplied with electricity is one mile from the generator-house, and the defect in the cable is half a mile from the generator-house, then the current which can pass at the defective place has only a circuit of half the distance it was intended to have; and not only that, but it avoids the resistance, &c., of the motor. Suppose the current at the generator had a voltage of 660, and the drop in the circuit was represented by 60 volts, then the voltage at the motor would be 600, and if there was a short-circuit the motor would be cut out, and the only resistance would be that of the cable of half the length, over which the drop would be 30 volts for the number of ampères in the ordinary current. But we have 660 volts at the generator, which is equal to forcing a current twenty-two times as great as the normal current through the short-circuit. This will quickly cause a conflagration at the place where the current passes from the cable to the earth, or across from one cable to the other in case the two cables are close together. We thus have a fire lighted in the mine which can only be stopped by the stoppage of the current by some automatic apparatus at the generator, or by the man in charge noticing the increase on the ampèremeter or some other sign. If before this happens the timber or coal has been fired, the salvation of the mine depends upon some man being at hand to extinguish the fire. In the case of main cables, the automatic cut-out should always act immediately. In the case of a branch cable, the automatic cut-out (at the generator-house) may act; but that will depend on the relative size of the branch cable to the main cable, because the automatic cut-out on the generator can only act in consequence of the current exceeding the normal amount. But there might be an excessive current on a branch cable, whilst the total actual current was below the normal. It is therefore necessary that there should be an automatic cut-out on each cable of each branch, so that in case of an excessive current passing along any branch cable it should be immediately cut out. This automatic cut-out should be as much part of the necessary apparatus as the use of a safety-lamp is in a mine known to contain firedamp.

The ordinary branch cable in a mine is insulated with vulcanised indiarubber, and protected by wrappings of tape and braid. In case there should be a short-circuit, this stuff is easily inflammable, and if it should be in contact with dry wood or coal, a fire might be produced instantly. Every experienced mining engineer is aware that it does not take long to produce a fire. Coal, timber, brattice-cloth, or coal-dust, has been often fired by an explosion of gas, therefore it is possible for a flame of very short duration to set fire to a mine.

The liability to firing from a sudden flame in the cable would be reduced to a minimum if the cable was armoured with iron wire. The armouring should be well earthed every hundred yards or nearer, because this would tend to prevent the burning of the braiding, tape, &c., caused by a sudden and quickly stopped short-circuit. Mine managers do not always think it necessary to adopt armoured cable for the sake of the additional safety, but there is no doubt that in a very warm and dry mine it is a mistake to run any unnecessary risk. It may, however, be borne in mind that where the mine is quite dry, and the positive and negative cables are some distance apart, and where neither of them is earthed, it is almost impossible for a short-circuit to take place between two well-protected taped and braided cables, unless there is some accident or mischief. A short-circuit can only take place by both the conductors being connected with the earth at the same time. The armouring of the cable, by bringing a metallic conductor close to the copper, facilitates the making of faults and short-circuits, and makes detection and repair of faults less easy. On the other hand, it reduces the chance of injury by mischief or by violent accident.

Where the mine is wet, short-circuiting is much more likely to take place, because the timber and ground, being wet, become comparatively good conductors, and water making its way into the cable forms a wet track from the copper conductor in the cable to the timber or ground, and the slightest fault in the insulation may be the forerunner of a short-circuit. Happily, these conditions are also those where a general conflagration is not likely to take place. The main cables, where there is a considerable current, are often insulated with paper which has been saturated with some waxy and oily compound. This paper, with its compound, is much more durable than indiarubber. The paper covering is drawn into a lead pipe to protect it from water, as contact with water will destroy the insulation. In order to protect the lead, it is armoured, sometimes with a steel strip, like a tape, wrapped round, and sometimes with wires. Sometimes the wires are galvanised. This armouring will form an effectual protection against a great many accidents, and the galvanising saves the iron from rapid corrosion. When a steel strip is used, it is covered with yarn or tape and protecting composition, to save it from corrosion by water or damp air. The heavy lead-covered cable is laid either along the ground, or in a trench in the ground; and in the latter case it may be covered with clay to keep out water, and also to provide a non-inflammable material in proximity to the cable. A cable laid in a trench is safe from injury even from the heaviest fall of roof, and no cable suspended from props can be regarded as safe from the effect of a fall of roof. The cable may be laid in an iron pipe in order to protect it from falls of roof, or accidental or mischievous blows, or damage by coal waggons getting off the road, &c.

Sparking at Switches.—Another source of danger is the sparking at the switches which is liable to occur when using either alternating current or continuous current. This danger may be diminished by putting the switches into strong iron boxes, and working them through stuffing-boxes, the space inside the box being so small that no large amount of explosive gas could be inside, and the openings on the outside being so small that if there were any explosion of gas inside the flame would not be able to pass through the openings. Another plan is to work the switches in oil or water (see page 104). Each of these methods has its advocates.

Short-circuiting with Coal-cutting Machines.—Some of the precautions above named are not practicable in dealing with electric coal-cutting machines. But there is no reason why the switches in the gates should not be protected, either in air-tight boxes or by oil. The cables used in the face may be armoured or leather covered, and the connections on the machine may be such as to make short-circuiting almost impossible.

Short-circuiting with a coal-cutting machine is most likely to be produced by some mistake in connecting the cables to the machine. This might be made impossible if there are only two places on the machine to which the cables can be attached. There is of course always a danger of sparking with the motor, but there is also a danger with the cutting parts of the machine striking hard substances, so that the additional danger from an electric spark is not perhaps very serious. The real danger to be avoided is that of a short-circuit above referred to.

No amount of care, and none of the precautions above named, will entirely eliminate the danger arising from the use of electricity in mines containing inflammable gas, or liable to blowers of fire-damp. All that is possible is to treat the fire, or possibility of fire, in the electric circuit in the same way as a fire in a lamp is treated in a safety-lamp when it is covered with wire gauze. The fire is there, but it is rendered harmless. The electric circuit is much more complicated, and for its safe management requires much greater foresight and knowledge. On the other hand, the electric circuit is only introduced into parts of the mine, and into those parts which are considered quite free from inflammable gas, and is only used when the examination of the mine by the deputies with their safety-lamps has shown that it is free from gas. The safety-lamp, though much simpler, is deliberately introduced by the deputies into parts of the mine which are likely to contain gas, for the purpose of exploration and estimation of the percentage of carburetted hydrogen; but no colliery manager in his senses will deliberately take an electric current into any part of a mine where he does not know as a fact that there is no gas, and that the possibility of gas occurring in that place is remote in the extreme. The difference between the danger from gas in contact with an electric current and the danger from coal-dust, dry wood, coal or shale, is that gas may be fired by a single spark of momentary duration, such as might occur at the fracture of a cable, or by the movement of an unprotected switch, or from a great variety of accidents, and before any automatic cut-out could stop the circuit; and indeed the action of the automatic cut-out itself would be liable to cause a spark which might fire gas in the vicinity unless the instrument was put in a case so arranged as to preclude the possibility of firing gas outside; whereas the danger from coal-dust and other inflammable materials arises only from more prolonged heat or fire. The coal-dust may be fired without any visible signs of heat in the electric circuit, but the heat must be continued for some time, and this should be prevented by a properly arranged system of cut-outs.

Prevention of Accidents due to Short-circuiting.—Two classes of injurious action result in short-circuiting. One may be called permanent, and the other accidental. In class No. 1, the chief cause is the gradual deterioration of the insulation owing to inherent defects in the insulating material, which tends to decay, the decay being often facilitated by heating of the cable. With the deterioration of the insulating material there is an increased tendency for the current to pass through the material, and thus in course of months or years the cable that was perfectly good when laid down becomes quite useless and dangerous. The other permanent causes are those due to the attack of water or damp air, or corrosive gas. The effect of water is to corrode the iron armouring, and to dissolve or otherwise injure the coverings of fibrous material, bitumen, lead, and paper, and in this attack the quality of the water is a matter of the utmost importance. The attack of damp air is similar. The attack of corrosive gases can seldom arise except from the smoke due to the combustion of coal or shale, and would happen in a furnace shaft, or in any other atmosphere charged with smoke. In an upcast shaft with a furnace at the bottom, the fumes of sulphur are likely to mix with water on the shaft side, and thus form a highly corrosive mixture.

The accidental causes are storms on the surface, and many other matters of uncertainty which it is not necessary to detail; in the shafts falls of coal-tubs, breakages of ropes, contact with cages, &c.; and in the roadways of the mine damage by coal-waggons getting off the road, falls of roof, upheavals of the floor, blows from pickaxes, shovels, &c. Many people advocate the use of concentric cables, on the ground that if a short-circuit occurs the fire is confined to the cable itself. Others advocate the use of separate cables, on the ground that short-circuiting is less likely to occur from a violent accident: thus, a heavy fall of roof breaking a concentric cable in two or crushing it flat would almost certainly cause a short-circuit at the point of fracture or crushing, but if there were two separate cables it would be necessary that each cable should be simultaneously so fractured as to be connected with the earth before a short-circuit could take place. If these two separate cables were in separate roadways it would be exceedingly improbable that simultaneous fractures would occur from falls of roof; and even if the two separate cables were in the same roadway, but on opposite sides, it is probable that one of the cables would escape fracture.

Detection of Faults.—It must, however, be borne in mind that it is quite likely, not to say probable, that in an electric mining circuit there is an undetected fault in one of the cables, because, as previously stated, there can be no short-circuit unless each cable is connected with the earth, so that a fault, however bad, in one cable will probably escape notice altogether until the other cable has some fault made in it. If, therefore, we wish to reduce the chances of accident to a minimum, care should be taken to maintain all the cables always in perfect condition, so that no short-circuit can possibly take place except by sudden injury to both the cables at once. If this care is taken, not only are the dangers reduced to a minimum, but the liability to stoppage of work through failure of the electric circuit is also reduced to a minimum, and the cost of maintenance and repairs of the cables is not increased in the slightest degree, because all faults have to be repaired at some time, and everybody will admit that it is much cheaper to repair them before harm has arisen than afterwards. For this reason there should be a fault or 'ground' detector in each generator-room, so that the man in charge can at once detect any defect in insulation in any conductor in any part of the mine or premises connected with his generators. This defect of insulation being only in one conductor of the circuit, which is not earthed, will not cause any damage, and if it is repaired before any defect occurs in the other conductor, no harm will have happened. This detector might be placed in duplicate in the manager's office on the top, and also at some convenient place at the pit bottom, so that attention would be immediately called to any defect in any one of the cables, and the underground manager would then be able to telephone up to the engine-room for information as to the position of the fault in the cable, and would be able to give directions for the repair of that fault the next time that that cable was out of use.

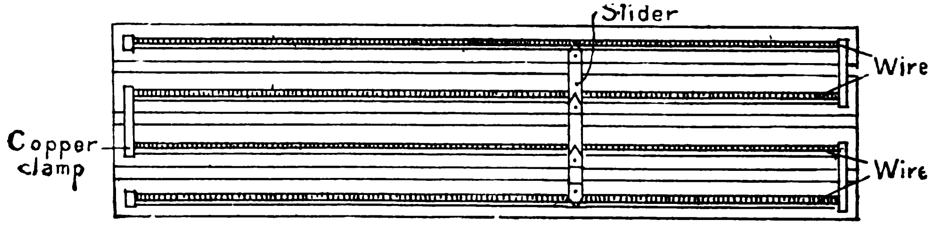
Position of Fault.—The mere knowledge that there is a fault somewhere in one part of a circuit would be of very little use to the manager of the mine or electrician in charge. He might be entirely unable to ascertain the place of the fault by simply looking at the external casing or feeling for damages, and particularly in the case of an armoured cable, in which it would be impossible to detect any defect in the insulation; all that he might find would be some damage to the exterior. It is therefore necessary to ascertain the position of the fault by means of suitable electrical apparatus.

Measuring Position of Fault.—The position of a fault in a cable is found by measuring the resistance of the cable from the generating station to the fault. For this purpose the apparatus known as Wheatstone's bridge is used. This consists of:

(1) A galvanometer, preferably a D'Arsonval mirror galvanometer, very sensitive and dead beat. This instrument has a moving coil which is suspended vertically by a fine wire, and has attached to it a small mirror, and when a current passes through the instrument the needle is deflected and the mirror with it. A small lamp is so placed that it throws a ray of light through a lens on to the mirror, which reflects the ray as a spot of light on to any convenient mark or scale, the motion of the spot of light following the motion of the needle. It is necessary to arrange a dark place for the use of this instrument. Instead of this, a 'detector' may be used, which is a sensitive portable galvanometer, in which the deflection is shown on a needle without a spot of light being necessary.

(2) A battery consisting of a few galvanic cells, or an accumulator cell.

FIG. 168.



BRIDGE WIRE.

(3) A wire of German silver or other high-resistance metal, at least a yard long and preferably several yards long; the longer it is the more accurate will be the result, provided that it is of sufficiently uniform cross-section. This wire is stretched in several lengths along a scale which may conveniently be divided into millimètres. Fig. 168 shows a convenient form of this wire, or, in place of the clamps joining the ends of the several sections of wire, it may be passed round pulleys, and contact made by means of knife-edges attached to copper bars, short-circuiting that part of the wire which passes round the pulleys; by this means a uniform stretch is given to all parts of the wire. This is known as the bridge wire.

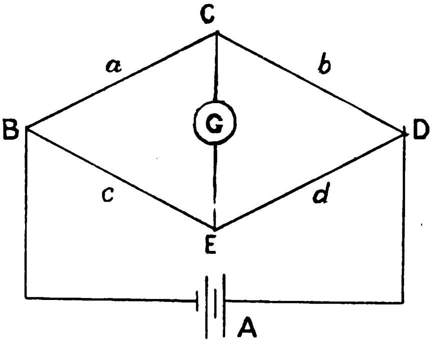
(4) A 'slider,' so arranged as to make contact with the wire at any point, which point can be accurately read on the scale. If the wire and scale are mounted on a board this contact may be conveniently mounted on a wooden slider running in a groove on the board.

A diagram showing the principle of the Wheatstone bridge is given in fig. 169. Current from the battery, A, passes to the point, B, and divides between the two paths, B C D and B E D, in a ratio depending on the resistances, *a*, *b*, *c*, and *d*. The galvanometer, G, is connected between the points C and E, and when the resistances, *a*, *b*, *c*, and *d*, are such that

$$a : b :: c : d,$$

then the points C and E must be at the same potential, and no current can flow through G. Thus, if the ratio $a : b$ and the value of *c* be known,

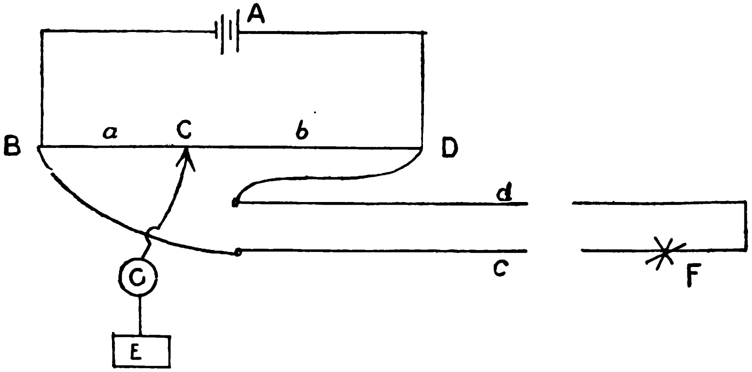
FIG. 169.



PRINCIPLE OF THE WHEATSTONE BRIDGE.

the resistance, *d*, can be determined. For the purposes of this test[1] the two leads at the far end of the line are connected together, and the bridge connected up as in fig. 170.

FIG. 170.



TESTING BY MEANS OF THE WHEATSTONE BRIDGE.

The two parts of the bridge wire on either side of the slider form the resistances, *a* and *b*, and their ratio is that of the lengths of wire as read on the scale. One terminal of the galvanometer is connected to the slider, C, the other to earth—*i.e.*, to some line of piping or to a plate buried in damp earth or a pond; earth corresponds to the point, E, in fig. 169, having no appreciable resistance. The battery is connected to the ends of the bridge wire, and the ends of the cables to the points, B and D. The two parts of the cable (in one of which is included the end connection) on either side of the fault form the resistances, c and d. The point, F, where the fault is situated, is electrically equivalent to the point E in fig. 169. The slider, c, is moved about until on making contact there is no deflection of the galvanometer; this shows that the relationship $a : b = c : d$ has been established. The ratio, $a : b$, is read off on the scale, and the position of the fault can now be calculated if the sectional area of all parts of the cable and the lengths are known. Take first the case in which the area is the same throughout.

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[1] The apparatus may be fixed at the generating station, or at the terminals of any cables under test, wherever they may be.

Let the resistance of a yard of cable be R ohms, and let the distance from the generator to the end of the cable be l yards, the total length of cable being $2\,l$ yards; $c =$ resistance of cable from B to fault; $d =$ resistance of cable from D to fault. Then

$$\frac{c}{d} = \frac{a}{b} \text{ and } c = \frac{a}{b} \times d,$$

$$\text{also } c + d = \mathrm{R} \times 2\,l;$$

$$\therefore \left(\frac{a}{b} + 1\right) d = 2\,l\,\mathrm{R},$$

$$d = \frac{2\,l\,\mathrm{R}}{1 + \frac{a}{b}}.$$

The length of cable having resistance d is $\frac{d}{\mathrm{R}}$;

$$\therefore \text{ length of cable to fault} = \frac{2\,l}{1 + \frac{a}{b}} \text{ yards.}$$

If the circuit is made up of cables of various sizes, the lengths of the smaller sizes must all be reduced to the lengths of the main cable which would have the same resistance. Thus, if part of the circuit is composed of cable having half the area of the main cable, its length must be multiplied by two before being added to the length of the main cable to form the length, l. The figure obtained as the distance of the fault will not in this case be the true distance, but to obtain the true distance the length of large-size cable must be subtracted from it, and the remainder divided by two; this will give the length of the small cable from the junction to the fault.

It is not sufficient to measure the resistance of one cable only to the fault, as the fault may itself (if it is not a 'de earth') have a resistance equal to a considerable length of cable. By this method, however, it is easily seen that the resistance of the fault is eliminated.

It will be seen that it is necessary to have all branches, except the one in which the fault lies, disconnected at the time of the test, so as to form a single continuous circuit. It is easy to find in which branch the fault lies by connecting them up separately one by one to the mains, until the ground detector indicates a fault. For this purpose, as for many others, it would be convenient to have a telephone system all over the mine.

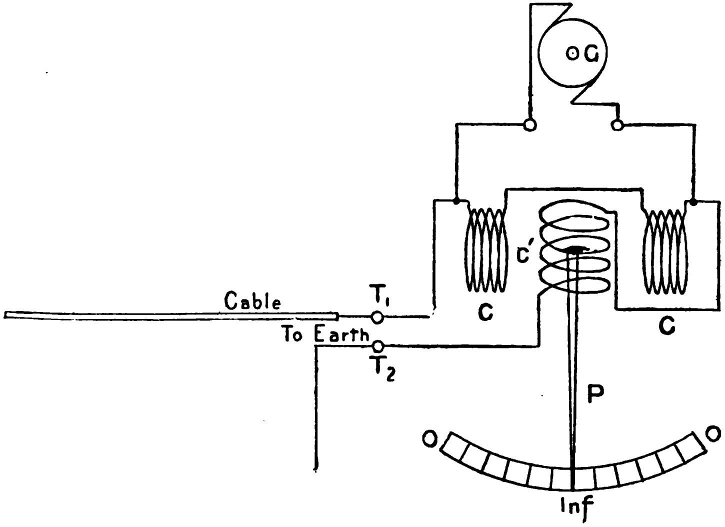
The position of a fault having been located, it will be the business of the electrician to see that it is repaired at the earliest possible time. If this system of testing the cables and repairing them is carried out thoroughly, it will be hardly possible for a short-circuit to occur, except as the result of some serious accident to the mains, or mischief, and the repairs will be effected at the minimum possible cost.

Another plan which is frequently adopted for keeping the insulation in order is to make insulation tests of the circuits at certain intervals—say, every week. For this purpose the ohmmeter, an instrument for measuring very large resistances, is used; it measures the resistance of the insulation, and if there is a serious fault in the circuit it will indicate an insulation resistance of zero. If the insulation is in perfect order it will register 'infinity'; not that when there is a fault the resistance is always zero, but it may be only a few ohms, which will not be indicated on the ohmmeter, or that when the insulation is good its resistance is really infinite, but it may be millions of ohms, which the ohmmeter cannot distinguish from infinity. One obvious disadvantage of this method over that explained above is that, one fault being formed subsequently to one week's test, another may occur before the next week and a short-circuit arise; whereas with the ground detector on the switchboard the first fault would immediately declare itself. The ohmmeter also forms a rough way of finding the position of a fault, as it can be taken round to different sections of cable and the insulation resistance of each determined; this method, although inferior in efficiency and safety to that above described, is adopted in many cases. With some installations even this is not done, no systematic attempt being made to find the first fault, the secondary ones being repaired as they show themselves. The risks involved in this plan are obvious.

The ohmmeter is also a useful instrument for testing the insulation of apparatus such as generators, motors, and switches. Its construction is shown in diagram form in fig. 171. G is a little magneto-generator turned by hand, which should give, when turned at a moderate speed, a voltage about the same as that of the supply at the station, because the so-called insulation resistance depends on the voltage (unlike a true resistance). These machines are now made to give voltages up to 1,000. The generator must be ordered for the voltage at which the installation is working. The generator sends current round two circuits which are connected in parallel; one circuit is formed by the two coils, C C, which control the position of a soft iron needle pivoted and attached to the pointer, P. The tendency of this current is to point the needle along the axis of the coils, C, and cause P to point to the part of the scale marked 'Infinity.'

The other circuit is formed by the coil C′ (the axis of which is at right angles to that of the coils C), the cable under test, its insulation, and the earth. A current passing round this coil tends to deflect the needle along its own axis, and the position taken up by the pointer is determined by the relative strength of the currents in C and C′. The current in C is directly proportional to the voltage generated by G, and the current in C′ is proportional to this and to the conductivity of the insulation of the cable. Thus, the position taken up by the pointer depends solely on the insulation resistance of the cable, and is independent of the rate at which G is turned (which determines its voltage), an increase in voltage, and consequent increase in current, taking equal effect in each circuit, and therefore the needle is not affected by such increase. The effect of voltage on the insulation resistance pointed out above does not have any serious effect with the small range of voltage which would correspond to turning the handle a little too quickly or too slowly.

FIG. 171.



OHMMETER.

It is not always necessary that the insulation of the circuit should be considered unsatisfactory if the ohmmeter does not register 'infinity.' A less value may be quite good enough. A good rule is that the insulation resistance in megohms should not be less than the figure obtained by dividing 10 megohms by the number of ampères at full load. Thus, in the case given in the table (page 146) for a 400-volt two-mile transmission, the current was 186½ ampères. The minimum insulation resistance of this circuit should therefore be $\frac{10}{186 \cdot 5}$ megohms = ·0536 megohm = 53,600 ohms. If cable of 600 megohms per mile be used, the insulation of the cable (four-mile circuit) itself will be $\frac{600}{4} = 150$ megohms; but the fittings, switches, motors, &c., may each have an insulation equal to a few megohms, which will soon pull down the total insulation of the circuit.

Thus, if we have insulation of cable =	150	megohms	
10 motors, of insulation =	3	„	each
50 switches and fittings =	5	„	„

the total insulation resistance being R (and, as the conductivity is the reciprocal of the resistance = $\frac{1}{R}$), we have for conductivity :—

$$\frac{1}{R} = \frac{1}{150} + \frac{1}{3/10} + \frac{1}{5/50}$$

$$= \frac{1}{150} + \frac{10}{3} + \frac{10}{1}$$

$$= \frac{1 + 500 + 1500}{150} = \frac{2001}{150}$$

And $$R = \frac{150}{2001} = \cdot 075 \text{ megohm.}$$

And this might easily be reduced further by a little bit of slightly defective insulation, or damp.

In making a test of the insulation of a circuit, the terminal, T_2, is connected with the earth—a water-pipe forms a good earth connection—and great care must be taken to be sure that it is a good earth, as upon this depends the efficiency of the test. Care must be taken that all the connections of the circuit are made in such a way that the terminal, T_1, of the ohmmeter is in electrical connection with every conductor of any description which forms a part of the circuit when it is at work. Thus, if it is desired to include the generators in the test (and this should be done if practicable), all connections must be made as if the entire plant were in operation; the terminal, T_1, is then connected to any convenient point in the circuit—such as a switch terminal on the switchboard—and the test is made; an open switch somewhere may cause only a part of the circuit to be included in the test, and the resulting insulation resistance will be higher than is actually the case for the entire installation. It is advisable before using an ohmmeter to test the voltage given by the generator on a voltmeter, so that the proper speed at which to turn the handle may be known. The ohmmeter may be taken to any part of the circuit and connected to any part of it, or to any separate generator or motor, or part of it. For instance, it may be connected to the windings of the field magnets, or to the armature, and each may be tested separately, and each branch line may be tested separately by opening the switches connecting with the rest of the circuit.

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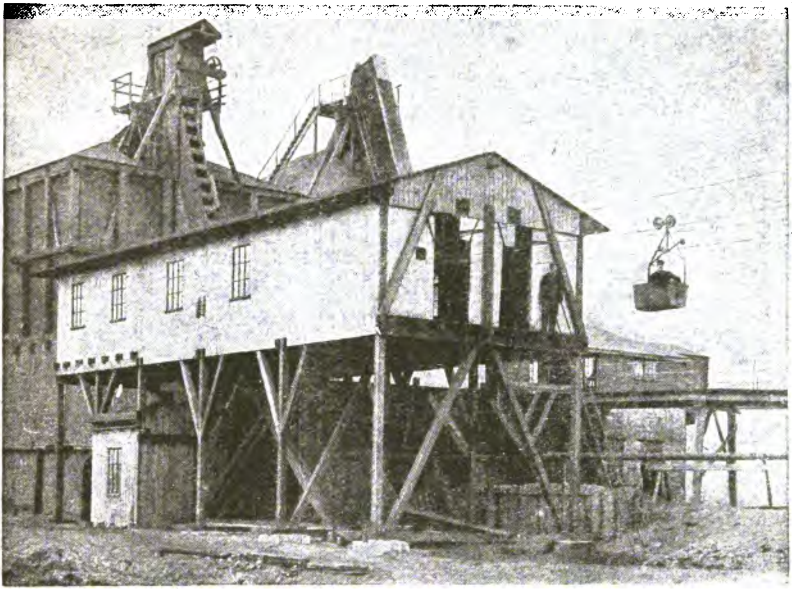

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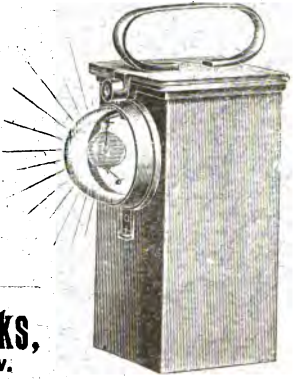

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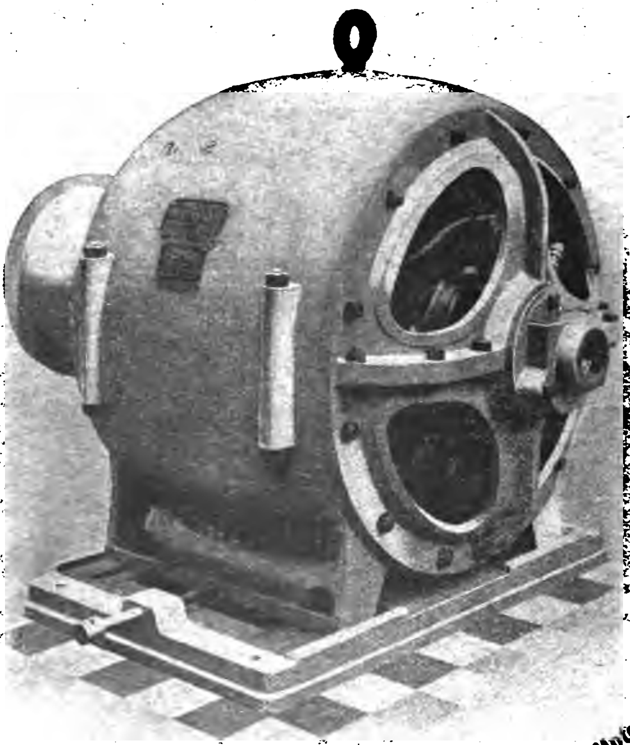

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